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**FINAL REPORT**

**DEVELOPMENT OF A**

**WEIGHT/SIZING DESIGN SYNTHESIS**

**COMPUTER PROGRAM**

---

28 FEBRUARY 1973

MDC E0746

**VOLUME I**

**PROGRAM FORMULATION**

SUBMITTED TO  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LYNDON B. JOHNSON SPACE CENTER  
HOUSTON, TEXAS 77058

CONTRACT NAS 9-12989

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**CORPORATION**



**DEVELOPMENT OF A WEIGHT/SIZING DESIGN SYNTHESIS  
COMPUTER PROGRAM - FINAL REPORT**

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**FOREWORD**

The Weight/Sizing Design Synthesis Computer Program was developed by McDonnell Douglas Astronautics Company - East under Contract NAS 9-12989 for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas. The contract involved a study to derive basic weight estimation relationships for those elements of the Space Shuttle vehicle which contribute a significant portion of the inert weight. These relationships measure the pacing parameters of load, geometry, material, and environment. The weight estimation relationships are then combined into the Weight/Sizing Design Synthesis Computer Program.

This report is submitted in three volumes:

- I            Program Formulation
- II           Program Description
- III          User Manual

This volume contains the definition of the Weight/Sizing Design Synthesis Computer Program, along with the rationale leading to its development. Included is a listing of the weight scaling models, the physical description of the equations, and supporting weight data.





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The following McDonnell Douglas Astronautics Company - East personnel were the major contributors to the technical contents of this study.

L. M. Gnojewski/R. W. Ridenour	Program Coding/Assembly Integration
B. A. Grob	External Tank & Empirical Equations
J. J. Morgan	Wing
J. M. Garrison	Structure Models

The Technical Monitor for the National Aeronautics and Space Administration, Mr. Norman A. Piercy, of the Engineering Technology Branch, provided valuable guidance and direction throughout the study.



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# DEVELOPMENT OF A WEIGHT/SIZING DESIGN SYNTHESIS COMPUTER PROGRAM - FINAL REPORT

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## 1. INTRODUCTION

The primary objective of this study was the development of a Weight/Sizing Design Synthesis Methodology to be used in support of the main line Space Shuttle Program. This methodology has a minimum number of data inputs and quick turn around capabilities consistent with the objective of enabling the NASA to rapidly: (a) make weight comparisons between current Shuttle configurations and proposed changes, (b) determine the effects of various subsystems trades on total systems weight, and (c) determine the effects of weight on performance and performance on weight.

We have used the technology developed during the Space Shuttle Phase B Program as our starting point, and expanded this technology into a workable family of weight estimation models tailored to the parallel burn Orbiter with an external LOX/LH<sub>2</sub> tank and a solid rocket motor booster. These models permit rapid weight and sizing calculations to be made with sufficient accuracy to measure the load, material, geometry, system configurations, and environmental parameters of interest to the Shuttle Program.

The study was organized into six tasks conducted in three distinct steps. The first step was to identify and deliver baseline programs (Task 1), and to review existing technology to identify each equation and to scope the effort required to develop each element (Task 2). Our starting point was the existing CASPER (Configuration Analysis, Sizing and PERformance) program, developed for a fully reusable Space Shuttle, and APSE (Analitical Parametric System Evaluation), which is an expanded version of CASPER, capable of multiple vehicle baseline configurations, and the VSP (Vehicle Sensitivities Program), developed to provide vehicle sensitivities. These baseline programs, along with informal user guides, were delivered to the NASA at the initial review on 30-31 August 1972.

The second step of this study, Tasks 3, 4, and 5, was to develop the required weight/sizing equations. We concentrated our efforts on those elements which contribute a significant fraction of the inert weight, and have a significant interface with the major load, material, and configuration parameters of the Shuttle. We identified these key elements as the wing and tail torque box, the body basic structure, the landing gear structure, the external tank, and the propulsion system inerts. The models for these key elements are developed (Task 3) from analytical relationships to a level consistent with overall input data requirements and required output accuracy. The remaining elements, such as the

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Thermal Protection System, Controls, Power, and Avionics, are represented by empirical relationships developed (Task 4) from existing models, hardware data, or Shuttle study data. Accuracy is demonstrated (Task 5) at both system and subsystem levels.

The third step, Task 6, refined the logic of the baseline APSE program, and oriented it to the current configuration of an external tank orbiter with a solid rocket motor booster. Additional work consisted of incorporating the developed equation into the refined program and installing it on the JSC UNIVAC 1108 computer.

The results of this study will provide the NASA with a weight/sizing computer program that: (a) can analyze the current configuration and ongoing efforts, (b) provides various vehicle sizing options, including size to payload, size to gross weight, and size to critical mission. The program will compute delta payload or delta performance with provision for constant thrust or T/W ratios, and (c) provide gross weight sensitivity to various system parameters, including payload weights and volumes, on orbit  $\Delta V$ , system inert weights,  $I_{SP}$ , and thrust level.

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2. APPROACH

Step 1, encompassing Task 1, Identify and Deliver Baseline Programs, and Task 2, Review Existing Technology to Identify Each Equation and Scope the Effort Required to Develop Each Element, was utilized as the basis for formulating the Weight/Sizing Design Synthesis Computer Program. This step defined our starting point and depicted our anticipated results.

Step 2, including Task 3, Development of Analytical Models for Key Elements, Task 4, Refinement of Empirical Models for Remaining Elements, and Task 5, Weight Model Accuracy, derived the weight-estimation models to be used in defining the orbiter, booster, and external tank modules.

Step 3 is essentially the culmination of the study. This step (Task 6) formulates the Weight/Sizing Design Synthesis Computer Program. This is the Executive Sizing PERFORMANCE (ESPER) program.

The ESPER program is a multioption sizing/synthesis program geared to the Solid Rocket Motor (SRM) Booster in parallel with an external hydrogen/oxygen tank orbiter for either the easterly (28-1/2 deg inclination) polar (90 deg inclination), or resupply (55 deg inclination) missions. The program has two primary options:

- (a) fixed hardware, and
- (b) iterative vehicle sizing.

The fixed hardware option determines the payload capability of a given configuration. This allows the user to determine the effect on performance of configuration and/or criteria changes, either real or proposed.

The iterative vehicle sizing option physically sizes the vehicles for a given payload. It determines the size of the SRM and its propellant load, and the size of the external tank and its corresponding propellant load. The iterative procedure is based on either the sizing criteria of a fixed staging velocity or it will size the vehicle to a minimum gross lift off weight (GLOW). The minimum GLOW option is provided as it is generally associated with a minimum cost operation.

In turn, either of the sizing requirements can be run with a fixed thrust option in which both the booster and orbiter thrust are set at given values and the propellant requirements are determined, or the orbiter thrust can be fixed and the first stage thrust-to-weight ratio input. The fixed thrust-to-weight options determines the booster engine size, plus the propellant requirements.

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Each of the vehicles has several modes of analysis available. The orbiter, external tank, and booster weight can be determined by the option of detail analysis, detail analysis while maintaining a user input dry weight, or no analysis but simply utilizing an input weight to represent the vehicle. In addition, the external tank and the booster are represented by simplified equations in which the parameters of interest are curve-fit to determine the vehicle weight.

In addition to printing out the performance parameters, the option is available to print out the detail subsystems weights of each vehicle, providing a line item comparison with the current Shuttle vehicle. Another option would be a simplified printout, containing only the vehicle dry or burn out weight as listed in the performance parameters.

Two performance subroutines are tied into the ESPER program to allow the user to determine growth characteristics or vehicle sensitivities.

ESPER is fundamentally based on the control logic found in the Analytical Parametric Systems Evaluation (APSE) program delivered to NASA at ATP plus 6 weeks. APSE is primarily a multivehicle program in which many types of vehicles and configurations can be compared, i.e., fully reusable configuration, external hydrogen tank orbiter, pressure feed booster, series burn, as well as the current baseline solid rocket motor (SRM) booster with an external hydrogen/oxygen tank orbiter.

Inherent with the multivehicle concept are extremely simplified weight relations, as depicted in the APSE system sizing network (Figure 2-1). The weight equations in APSE consisted primarily of mass fractions, with the booster being a function of thrust and propellant load, the orbiter a function of thrust, and the external tank a function of required propellant. These mass fractions were derived from study point designs, and required continual updating to meet the ever changing criteria. With ESPER being based on the current baseline vehicle, and the multivehicle studies dropped, the major emphasis of this study was directed to the expansion of the weight relationships.

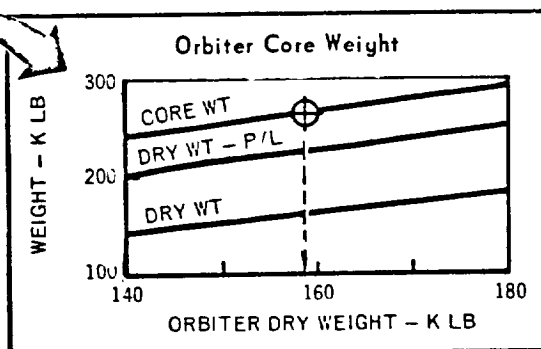
Figure 2-2 presents a simplified flow chart of the ESPER program. The program consists of three vehicle modules, two functional modules, and three performance subroutines. The vehicle modules contain the analytical and empirical equations and relationships required to completely define the orbiter and booster, and the external tank respectively. As noted in the introduction, these equations will measure the pacing parameters of load, material, and geometry. The functional modules describe the vehicle sizing and the trajectory analysis. The output



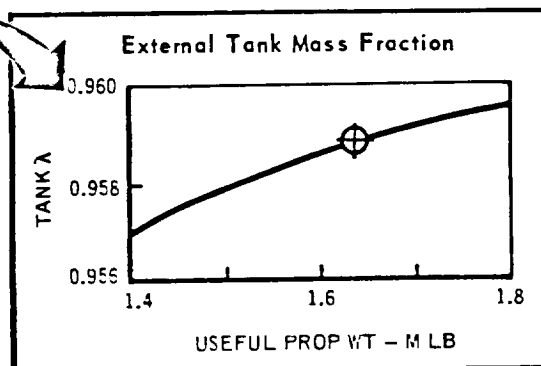
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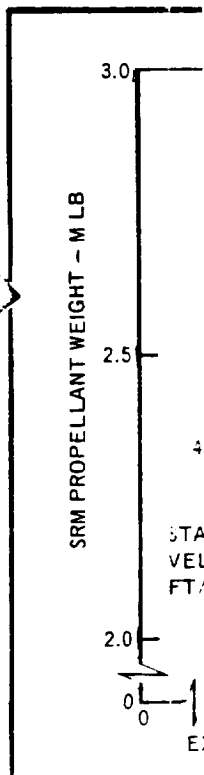
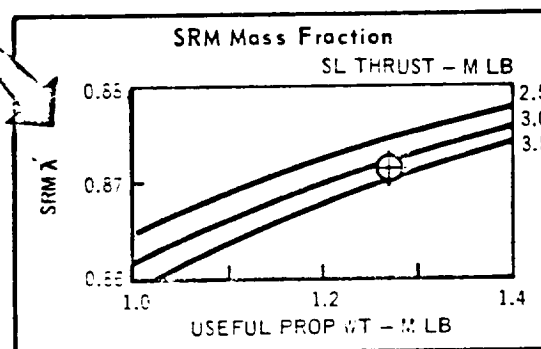
ORBITER SUMMARY	
	LB
DRY WEIGHT	158,878
CARGO	65,000
CREW AND EXPENDABLES	3,509
INERT WEIGHT	227,387
FLUIDS, PROPELLANTS	37,692
CORE (GROSS WEIGHT)	265,079



EXTERNAL TANK SUMMARY	
	LB
DRY WEIGHT	65,060
RESIDUALS	5,412
USEFUL PROPELLANTS	1,640,000
GROSS WEIGHT	1,710,472
$\lambda$	0.9588 $\lambda$



LAUNCH VEHICLE SUMMARY (PER SRM)	
	LB
STAGE HARDWARE	26,360
INERT MOTOR	140,402
RECOVERY SYSTEM	20,606
UNCERTAINTY/GROWTH	7,502
PROPELLANT WEIGHT	1,270,000
GROSS WEIGHT	1,464,870
BURNOUT WEIGHT	188,522
$\lambda$	0.8713



CONSTRAINTS:

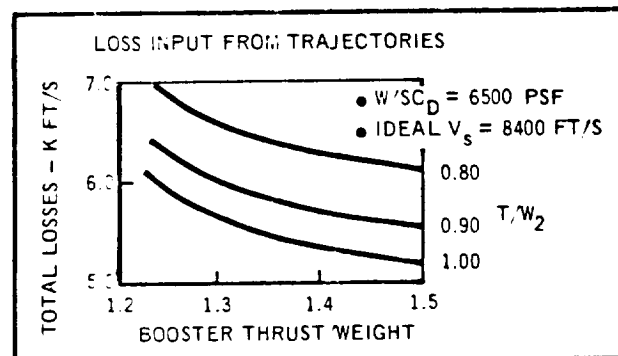
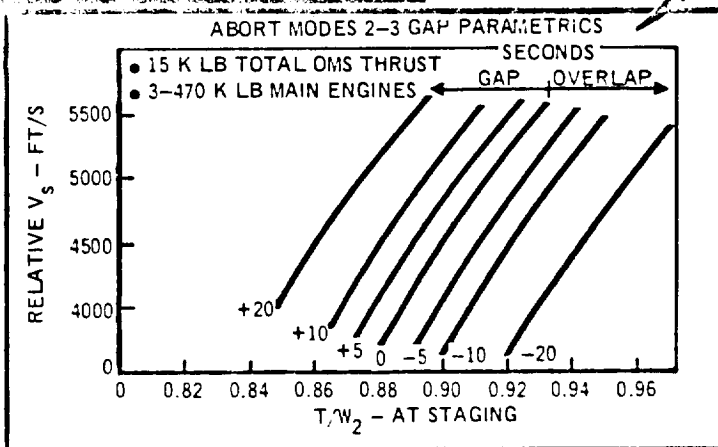
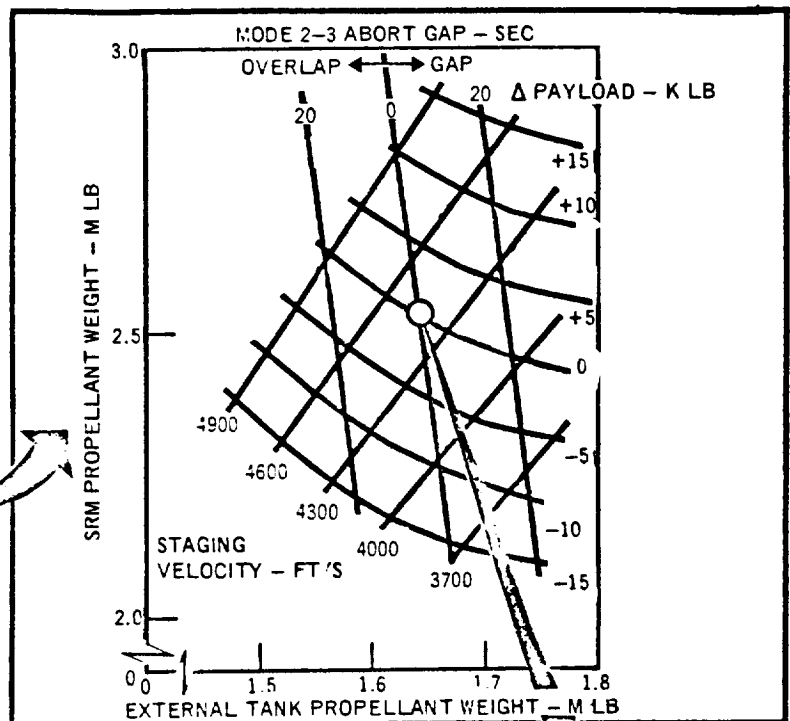
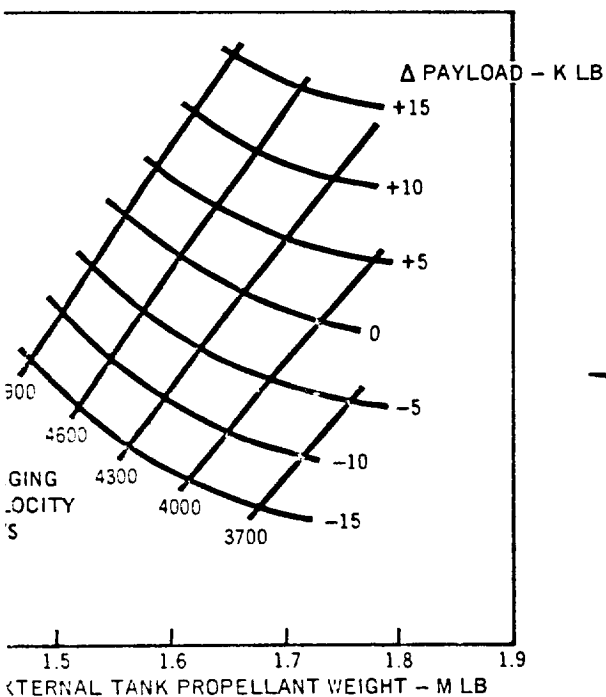


FIGURE 2-1 APSE SYSTEM SIZING PROCEDURE



### Propellant Loading Parametric



### System Summary

WEIGHTS (EASTERLY MISSION)	K LB
ORBITER	302.4
ABORT ROCKET	37.3
INJECTED	265.1
DRY	158.9
PAYLOAD	65.0
CREW AND EXPENDABLES	41.2
TANK	1710.5
USABLE PROPELLANT	1640.0
DRY AND RESIDUALS	70.5
SOLID ROCKET MOTORS	2 x 1464.9
PROPELLANT	2 x 1270.0
INERT	2 x 194.9
GROSS	4942.6



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is an analyzed vehicle which, when coupled with the performance subroutines, will allow the user to derive growth accommodations, sensitivities, and payload capabilities. These modules and subroutines operate under the logic and direction of the Control/Assembly program.

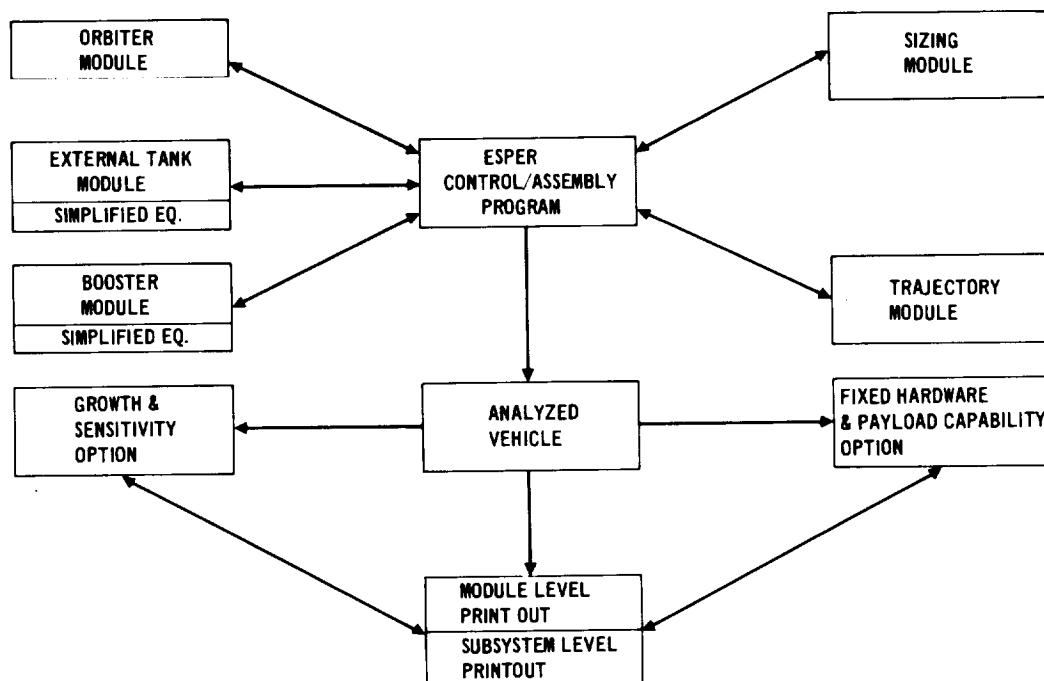


FIGURE 2-2 ESPER FLOW CHART

The APSE program was selected as the basic sizing logic after a review of existing sizing/synthesis programs. The review consisted of all available Space Shuttle Phase A, Phase B, and Extension Study data. In addition to the Space Shuttle Study reports, a total of ten additional reports were reviewed which might have had applicability to the weight/sizing effort of this study. The reports reviewed are:

- (1) "Space Shuttle Synthesis Program (SSP)", Report No. GDC-DBB70-002, dated December 1970, submitted under Contract NAS 9-11193 to NASA-MSC by General Dynamics Convair.
- (2) "Improved Scaling Laws for Stage Inert Mass of Space Propulsion Systems", Report SD 71-534, dated June 1971, submitted under contract NAS 2-6045 to NASA-ARC by North American Rockwell.
- (3) "Weight Analysis of Hypersonic Airbreathing Aircraft", Report GDA-DCB-64-089, dated December 1964, submitted under contract NAS 2-1870 to NASA-ARC by General Dynamics/Astronautics.



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- (4) "Hypersonic Aerospace Vehicle Structure Program, Volume II Generalized Mass Properties Analysis", Report No. AFFDL-TR-68-129, dated January 1969, submitted under Contract F33615-67-C-1300 to USAF-FDL-WPAFB by Martin Marietta Corporation.
- (5) "Weight Estimating and Forecasting During Conceptual Design", Report No. MSC-01259, dated November 1970. Submitted under Contract NAS 9-10326 to NASA-MSC by Martin Marietta Corporation.
- (6) Proceedings of Weight Prediction Workshops sponsored by Systems Engineering Group, Research and Technology Division, Air Force Systems Command, WPAFB, H. G. Kasten, Organizer for the Years 1965, 1966, 1967, 1968, 1969, and 1970.
- (7) "Optimized Cost/Performance Design Methodology", Report No. MDC E0005, dated 1 September 1969, submitted under Contract NAS 2-5022 to NASA OART by McDonnell Douglas Corporation.
- (8) "Structural Systems and Program Decisions", Report No. NAS SP-6008, Volume I, prepared by the Apollo Program Office, NASA.
- (9) "Vehicle Synthesis for High Speed Aircraft", Report No. AFFOL-TR-71-40, dated June 1971, submitted under Contract F33615-70-C-1109 to FDL, WPAFB of the USAF by General Dynamics/Convair.
- (10) "Parametric Weight Scaling Equations for Solid Propellant Launch Vehicle", Report SSD-TR-66-85, dated April 1966, prepared by J. E. Kimble, Aerospace Corporation for Space Systems Division, USAF.

A synopsis of these reports and the rationale for choosing the MDAC-E APSE program is discussed in depth in the midterm report. (Reference S)

To facilitate rapid turnaround and ease of updating for major configuration changes, the modularized concept was utilized. As these modules are entirely self-contained, they may be readily changed or completely replaced at the discretion of the user.

The Control/Assembly program integrates the vehicle modules and combines them in an iterative computational sequence for the orbiter, external tank, and booster. The specific weight relationships developed for each vehicle module and the ascent trajectory curve fit of velocity losses feed into this Control/Assembly program. The use of separate modules provide a systematic means of controlling the logic flow in the program. The ESPER control logic is shown in the flow diagram, Figure 2-3.

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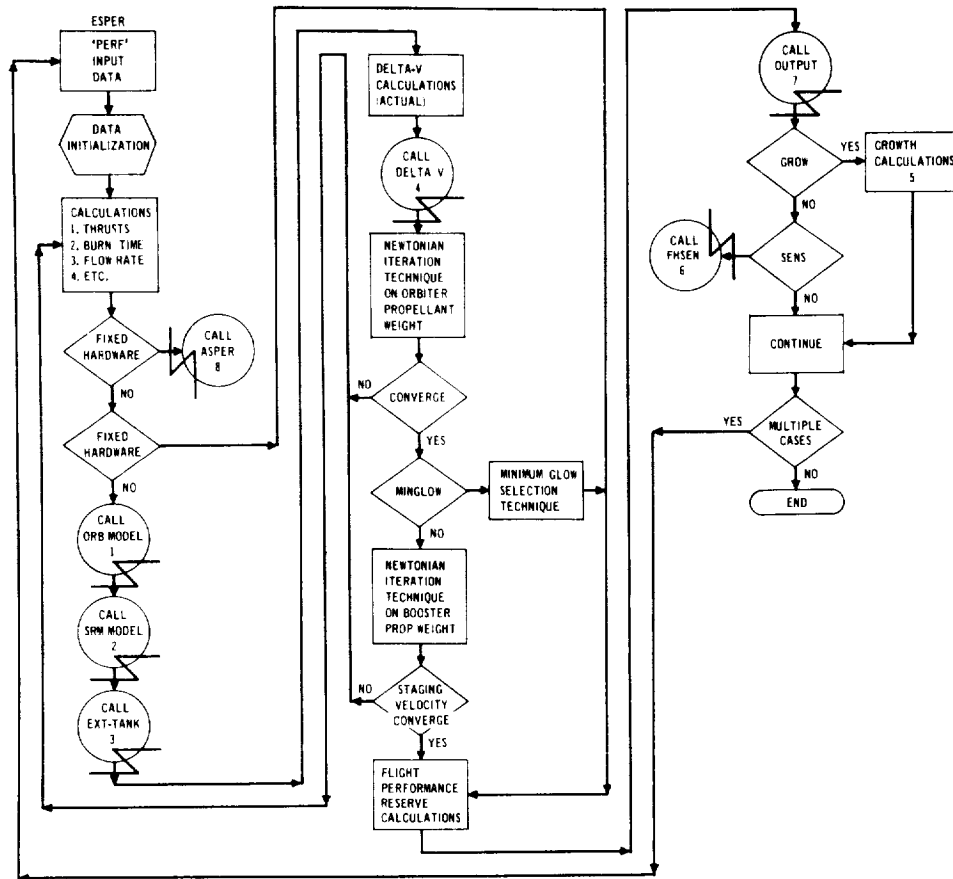


FIGURE 2-3 ESPER FLOW DIAGRAM

Vehicle Modules - The vehicle modules are made up of a series of independent subsystem models. The advantages, from a user standpoint, of this modularized system are unique. This concept allows the user to make subsystem modifications without affecting the rest of the module, and provides a means for replacing the subsystem models or the entire vehicle module with future routines obtained from the mainline Shuttle program. The user needs only to program the new module following a set of straightforward rules to insure adequate linkage, and to insure that every required function is accounted for.

Each vehicle module consists of the analytical and empirical weight equations so that each model represents a group weight of the NASA functional grouping. We used the NASA Phase B functional weight grouping (Figure 2-4) to assist in identifying the weight models to be developed, and in determining whether the model is analytical or empirical in nature. By defining our weight models as line items of the functional grouping, we have obtained a direct line-by-line comparison of our model data with the weight status reports of the main line Shuttle program. This comparison will identify for the user which areas of the



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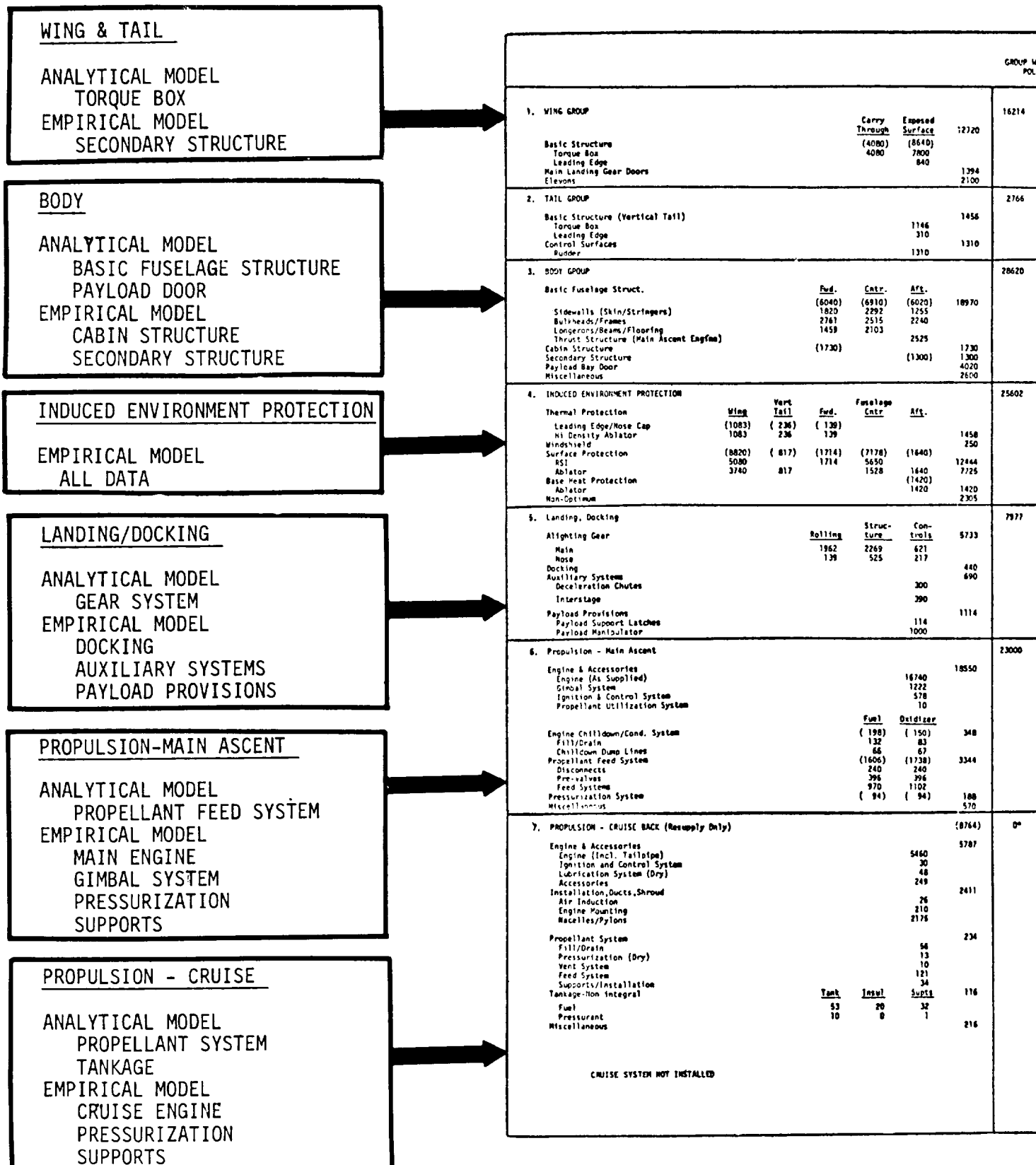


FIGURE 2-4 SURVEY OF WEIGHT MODEL DEVELOPMENT



<b>B. PROPULSION - AUXILIARY</b>							4483
		Att Control	3218	Maneu- ver	3265		
Thrustor Installation		( 616)		( 476)			
Thrustors		364		340			
Accessories & Install		252		136			
Propellant System		( 157)		( 252)			
Lines & Valves		112		180			
System Install.		45		72			
Module Structure		(1479)		(1084)			
Tankage		( 673)		(1156)			
Propellant		426		517			
Pressurant		247		639			
Miscellaneous		( 293)		( 297)			
<b>9. PRIME POWER</b>							4020
	Power Unit	Mts/ Install.	Prop Ink/Sys.	Con- trols			
Batteries	70				70		
Generators	232				232		
Auxiliary Power Unit (APU)	500	477	316	180	1473		
Fuel Cells	825	258	608	40	1723		
Miscellaneous					522		
<b>10. ELECTRICAL CONV. &amp; DISTR.</b>							2530
Equipment					249		
Distribution & Control					1519		
Supports & Install					679		
Miscellaneous					123		
<b>11. HYDRAULIC CONV. &amp; DISTR.</b>							1910
	#1	#2	#3	#4			
	( 343)	(343)	( 343)	( 343)	(1372)		
Primary Pumps & Reservoirs	76	76	76	76	304		
Valves & Res. Level Sensors	41	41	41	41	164		
Secondary Elec. Pumps	22	22	22	22	88		
Pumping & Fittings	88	88	88	88	352		
Circuitry	21	21	21	21	84		
Supports & Installation	95	95	95	95	380		
Miscellaneous					( 138)		
<b>12. SURFACE CONTROLS</b>							4997
	Primary Actuator	Secondary Actuator	Plumb/ Fts's	Circ- uitry	Supts/ Linkage		
	(8039)	( 160)	( 148)	( 525)	( 638)	(4510)	
Elevon	2070	80	112	247	254	2763	
Rudder	294	40	32	174	34	574	
Rudder Flair	675	40	4	104	350	1173	
Miscellaneous						( 487)	
<b>13. AVIONICS</b>							5730
		Equip- ment	Circ- uitry	Supts/ Install			
		(3359)	( 893)	( 733)	(4985)		
Guidance Navigation & Control		(1048)	( 265)	( 231)	(1544)		
Aeroflight		392	80	90	572		
Spaceflight		656	175	141	972		
Communications & Tracking		( 228)	( 44)	( 70)	( 342)		
Displays & Controls		(1159)	(356)	(210)	(1725)		
Operational Instrumentation		( 580)	(150)	(131)	(861)		
Payload Manipulator System		( 344)	( 78)	( 91)	(513)		
Miscellaneous					( 745)		
<b>14. ENVIRONMENTAL CONTROL</b>							6550
		Equip- ment	Plumb/ Fts's	Circ- uitry	Supts/ Install		
		(3428)	( 472)	( 67)	( 489)	(4456)	
Cabin Air Loop (Atmos. Revitalization)		398	213	5	27	643	
Autonics Bay Active Thermal Cntl.		135	6	10	14	165	
Cabin & Equip. Coolant Loops		883	217	25	88	1213	
Waste Management		206	2	3	20	231	
Water Management		198	11	10	12	231	
Pressure & Composition Control		239	10	8	20	277	
Hydraulic/APU Cooling System		113	8	4	14	139	
Space Radiator		1216	6	1	290	1512	
Misc. Equipment		40	—	1	4	45	
ECS Local Insulation						(1742)	
Miscellaneous						( 312)	
<b>15. PERSONNEL PROVISIONS</b>							800
Seats & Restraint System						320	
Galley & Emergency Equipment						80	
Furnishings						400	
		Cab- inets	Part- itions	Wall Covering			
		65	195	140			
<b>16. GROWTH/UNCERTAINTY (10% Less GFE)</b>							12008
Subtotal (Dry Wt)							(148807)
<b>20. PERSONNEL</b>							1200
Crewmen (4-90th Percentile & Suits)						868	
GFE Food and Equipment						332	
<b>21. CARGO</b>							40000
<b>23. RESIDUALS</b>							2156
	Ascend	Cruise	Maneu- ver	Att. Control	ECS/ Reactants	Hydr- aulls	
			247	191	917	601	
Subtotal (Inert Wt)							(192163)
<b>25. RESERVES</b>							12138
		6446	5454	241			
<b>26. INFIGHT LOSSES</b>							5443
	2650			1761	1032		
<b>27. USABLE PROPELLANT</b>							9383
		7311	2072				
TOTAL (Gross Weight)							(219127)

## PROPULSION-AUXILIARY

ANALYTICAL MODEL  
PROPELLANT SYSTEM  
TANKAGE  
EMPIRICAL MODEL  
AUXILIARY ENGINES

## MISCELLANEOUS SYSTEMS

EMPIRICAL MODEL  
ALL DATA

## FLUIDS

ANALYSIS BASED ON  
INPUT PERFORMANCE  
REQUIREMENTS.

ITERATED FOR FINAL RESULT



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program need updating or which elements of the reported weights require scrutiny. The major discriminator used to determine whether or not an item should be analytically or empirically derived was the relative weight of that component as compared to the total. (Figure 2-5).

As noted in the introduction, Task 3 was the development of analytical relationship for key elements. Many prediction methods have been developed and used in aircraft and spacecraft design over the last three decades. These range from simple weight to area or volume relationships to extremely sophisticated finite element models. The methods most often encountered in design synthesis programs have leaned towards the simple relationships, such as wing weight being a function of design weight, and some geometry parameters with a curve fit exponent.

$$WT = f (WT, AR, AREA, ETC.)^X$$

	PERCENT WEIGHT	ANALYSIS METHOD
WING	9	ANALYTICAL
TAIL	2	ANALYTICAL
BODY	26	ANALYTICAL
TPS	18	EMPIRICAL
LANDING/DOCKING	7	ANALYTICAL
PROPULSION	21	ANALYTICAL
PRIME POWER	3	EMPIRICAL
ELECTRICAL	3	EMPIRICAL
HYDRAULIC	2	EMPIRICAL
SURFACE CONTROLS	3	EMPIRICAL
AVIONICS	3	EMPIRICAL
ENVIRONMENTAL CONTROL	2	EMPIRICAL
PERSONNEL PROVISIONS	1	EMPIRICAL

**FIGURE 2-5 ORBITER MODEL DEFINITION**



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The typical fuselage, due to its complexity, is often treated even more rudimentarily with weight being simply a function of surface area and unit weight. The objective of our program is to have the capability to measure the major load, material, geometry, and configuration parameters, while keeping the variable parameters, and consequently computation time, to a minimum. Our approach to the solution of this task was to develop analytical weight prediction models for only those elements of significant weight that are directly affected by the pacing parameters. The analytical model will be at a level of sophistication adequate to accurately measure the effects of these parameters, yet simple enough that input data and computer run time are small.

The development of a structural analytical model follows three basic steps as illustrated by the Wing Weight Prediction Model, Figure 2-6. First, a simplified, mathematically workable arrangement of elements for the component to be estimated is developed, and the significant geometric factors which are to be investigated are established. Next, the external loads are derived and a means of scaling these loads with the vehicle characteristics is developed. Finally, the elements of the component are modeled to carry the internal loads which have been developed from the external loads.

Any analytical model will have a large number of parameters. Several steps have been taken to insure actual input data is minimum while consistent with capability to measure the significant factors. First, a common model is used for all structural components using shell structure. Second, careful attention is given to all parameters to insure that parameters that can be derived from other input data are calculated within the program, and third, in certain cases parameters which are unlikely to be varied for the Shuttle program, but may be required to obtain application to conventional aircraft or other vehicles, will be "fixed" in the program.

The models are not intended to yield an optimized structural design, but rather to provide data adequate to define reasonable weights and their sensitivities to the design and performance criteria applicable to each study or configuration considered.

The analytical relationships were used for the wing and tail torque boxes, the body basic structure, the landing gear struts, and the propulsion system of the orbiter module. Additionally, the tank and booster modules are primarily analytical.

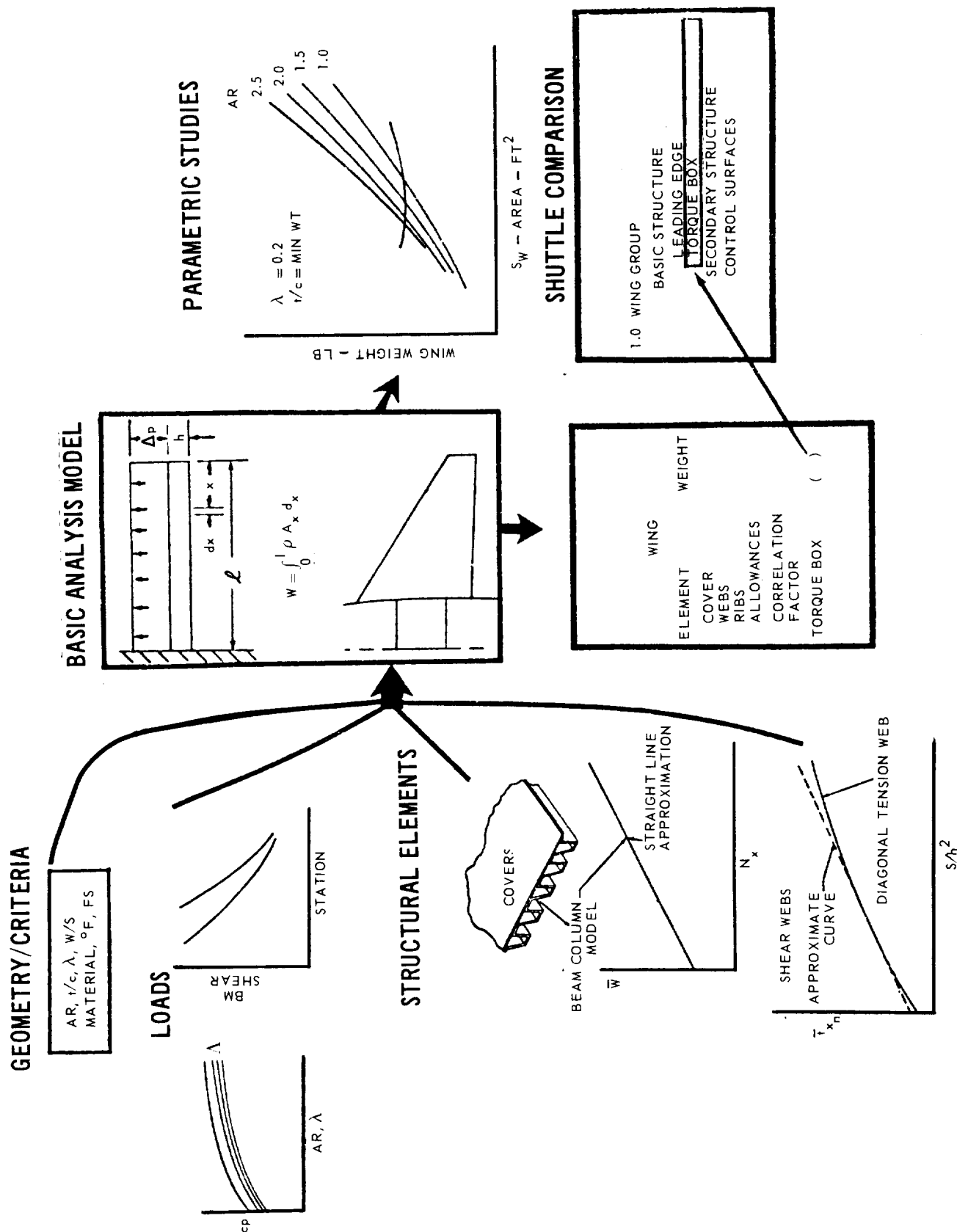


FIGURE 2-6 WING WEIGHT PREDICTION AEROSURF



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Empirical models make up the remaining orbiter dry weight. The emphasis in these models is on adequate accuracy with a minimum of input data, and use of simplifying assumptions which will result in significant reductions in computer storage and run time. The heading of empirical models includes curve fits to more sophisticated programs, ratioing of Shuttle detail design data points, curves through data points of comparable existing hardware elements, or a mixture of the above. Even the inputting of selected constants, such as avionics, has been categorized as empirical methods for the purposes of this discussion. Background data available for this task comes from several sources, including McDonnell Aircraft Company and Douglas Aircraft Company estimation work, and a host of papers and contracted efforts for weight estimation methods.

This empirical approach is used on secondary structural items of the wing group, tail group, and body group in order to completely weigh these assemblies. By combining these secondary items with the analytical weight models, the correlation of the completed body/wing weight (analytical plus empirical methods) can be made. Similarly, certain subsystems, such as Prime Power, Electrical Conversion and Distribution, Hydraulic Conversion and Distribution, Surface Controls, Avionics, Environmental Control, and Personnel Provision, will also be treated empirically. Current Shuttle work shows that although the total weight for the seven systems above is approximately 17 percent of the vehicle dry weight, these subsystems are not highly sensitive to the vehicle configuration. For this reason, we feel an empirical approach will satisfy the accuracy requirements for these systems.

Additionally, the external tank module and the SRM module include simplified equations derived by curve fitting the results of the detail equations for specific parameters and ranges of interest. The simplified equation is an optional usage of the program, and its purpose is to increase the flexibility of the program by reducing the input data and computer run time. Included in the program are basic simplified equations, but the option is available for NASA to replace them with their own equations, similarly derived, using parameters of their own specific interests. An example of this simplification would be the external tank mass fraction as exemplified in the APSE System Sizing Network, Figure 2-1. The data shown is a plot of a simplified equation for an external tank mass fraction as a function of usable propellant weight. Output, resulting from the utilization of these simplified equations, would, of course, not be at the detailed level as are the results of the analytical and empirical methods. The input data in general is geared to the Design Data Summary of the NASA Group Weight Statement.

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All modules requiring external data have their own NAMELIST input. The advantage of this method of input is that the user can modify individual modules without perturbing the overall input data list.

Sizing Module - The sizing model contains the iteration techniques capable of scaling the reference configuration to meet the major vehicle parameters of wing loading and volume. This iteration technique will scale the configuration to a fixed staging velocity, or to a minimum gross launch weight. Specific scaling rules in the vehicle modules establish the areas, volumes, lengths, etc., required to describe the resized configuration without resorting to extensive geometry analysis routines. The scaling effort of the orbiter includes the following elements listed in sequential order. The body can be "stretch" sized without changing body diameter; the body width can be increased or decreased, or there can be a combination of both. The wing reference area has two main options; a fixed area or a resized area to hold wing loading at a constant. The vertical tail can be sized to maintain a constant tail volume coefficient.

The external tank sizing will have three main options; size to propellant volume by varying length with diameter held constant, varying diameter with length held constant, or size to volume maintaining a constant length/diameter ratio.

The SRM module iterates on required propellant for the design mission, sizing the structure for a user input diameter.

Trajectory Module - The trajectory module contains the curve fits of an optimized trajectory, established by MDAC during the Phase B Shuttle program. These curve fit equations determine the total required velocity by defining the velocity losses. This is accomplished in several distinct steps:

- a) The ideal required velocity is determined as a function of first stage velocity, first and second stage thrust to weight ratios and the ascent drag parameter.
- b) The velocity losses attributable to the launch site altitude and the required mission inclination.
- c) A delta velocity correction factor which allows the curve fit equations to translate through the defined losses of an analyzed point design.

The equations are empirical relationships derived from parametric ascent trajectory shaping studies and are intended to be used for ideal staging velocities in the range of 8000 to 12000 ft/sec. Ascent losses have been shown to be a strong function of thrust/weight at lift-off ( $T/W_1$ ), and thrust/weight immediately after staging, ( $T/W_2$ ). Other significant correlation factors in the velocity loss

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equation are staging velocity ( $V_S$ ), first stage drag parameter ( $W/SC_D$ ), and launch site altitude ( $H$ ). All of the above parameters are self-explanatory with the exception of  $SC_D$ . The  $SC_D$  value used is between Mach numbers 1.2 and 1.5, where "S" is the frontal projected area of the mated configurations and  $C_D$  is the drag coefficient.

The velocity losses were curve fit for ease of interpolation when used for sizing studies. The coefficients of the multivariate, polynomial fit were evaluated by a least-squares technique. Each coefficient of the initial polynomial was tested for significance, and the least significant term was eliminated. This procedure was repeated until a minimum term polynomial was determined which had accuracy essentially equal to the original. The accuracy of the curve fit was then improved by conditioning the independent variables with natural logarithmic functions. However, if new data is curve fit, other functions may be more appropriate.

The curve fits are predicated on limiting values of the thrust to weight ratios and the ascent drag coefficient. These limits are:

- a) First stage thrust to weight is less than 1.60 or greater than 1.18.
- b) Second stage thrust to weight is less than 2.0 or greater than 0.70.
- c) First stage drag parameter is less than 12000 or greater than 1000.

If these limits are exceeded, the program selects the applicable limiting parameter and outputs a warning that the results are outside the bounds of the curve fit equations and the validity of the results is questionable.

Table 2-1 and Figures 2-7 through 2-10 represent the results of the parametric ascent trajectory studies used in deriving the velocity loss curve fits. This data is presented to be used as check points if it is desirable to change the curve fit equation to represent modified trajectories as the design progresses.

Performance Subroutines - These subroutines enable the user to compile the performance data of the reference configuration. These performance routines have three options; sensitivities, growth, and fixed hardware (payload capability).

The sensitivity data can be generated in two fashions. Rubber vehicle sensitivities can be derived for virtually any parameter by varying the selected parameter a specified increment, and making consecutive runs on the ESPER program. Fixed hardware sensitivities can be developed using a sensitivities subroutine, which is incorporated into ESPER.

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TABLE 2-1

ASCENT VELOCITY LOSSES

$V_1$ FT/SEC (IDEAL)	$(T/W)_1$	$(T/W)_2$	$V_L$ FT/SEC
8,000	1.20	0.70	8,620
		0.85	7,300
		1.10	6,495
		1.60	5,970
	1.40	0.70	7,520
		0.85	6,200
		1.10	5,395
		1.60	4,870
	1.60	0.70	6,910
		0.85	5,590
		1.10	4,785
		1.60	4,260
10,000	1.20	0.70	8,400
		0.85	7,080
		1.10	6,275
		1.60	5,750
	1.40	0.70	7,200
		0.85	5,880
		1.10	5,075
		1.60	4,550
	1.60	0.70	6,660
		0.85	5,340
		1.10	4,535
		1.60	4,010
12,000	1.20	0.70	8,250
		0.85	6,930
		1.10	6,125
		1.60	5,600
	1.40	0.70	6,950
		0.85	5,630
		1.10	4,825
		1.60	4,300
	1.60	0.70	6,460
		0.85	5,140
		1.10	4,335
		1.60	3,810

- (1) Polar Mission (50 x 100 NMI)  $i = 90^\circ$
- (2) Series Burn (Solid -  $I_{SP} = 268/\text{HiPC} - I_{SP} = 455$ )
- (3)  $W/SC_D = 4050 \text{ lb/FT}^2$  (Glow/ $SC_D$  MAX.)

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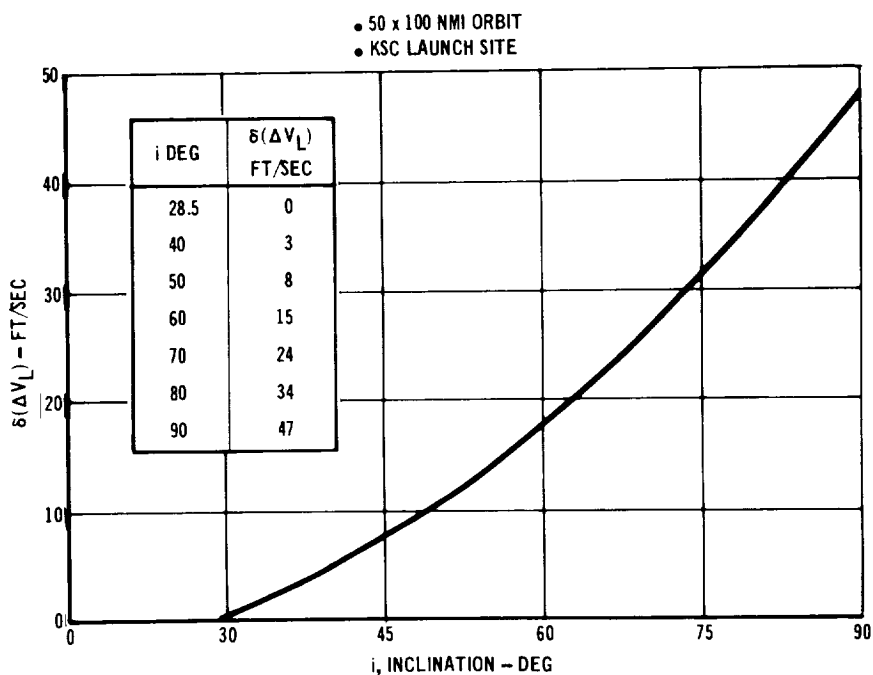


FIGURE 2-7 ASCENT VELOCITY LOSSES EFFECT  
OF ORBIT INCLINATION

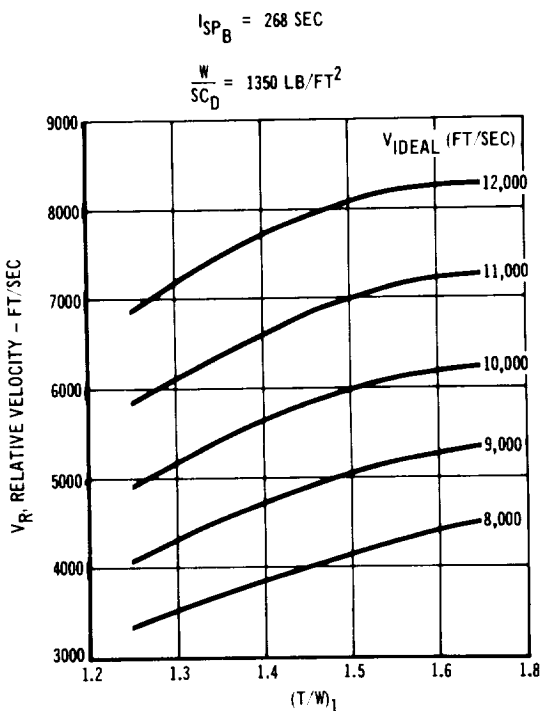


FIGURE 2-8 STAGING VELOCITY

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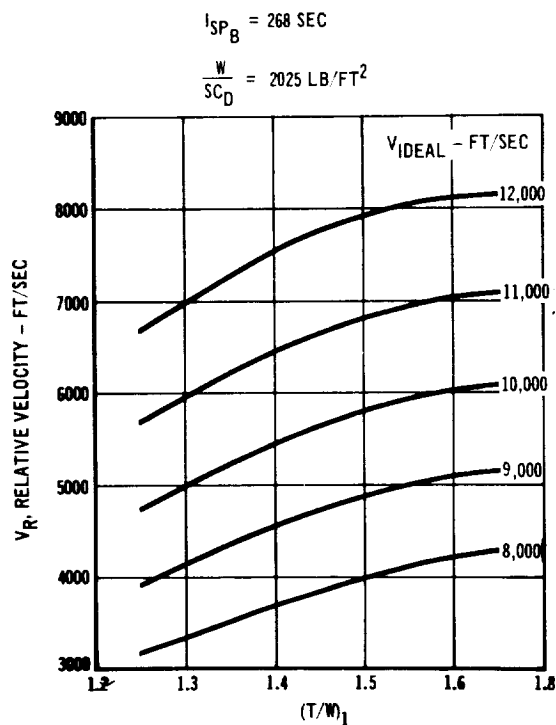


FIGURE 2-9 STAGING VELOCITY

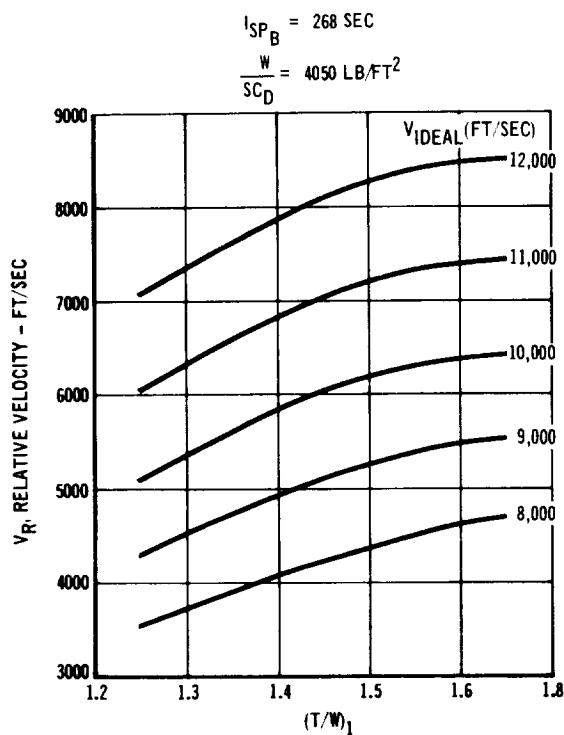


FIGURE 2-10 STAGING VELOCITY

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The growth option enables the user to grow the reference configuration in four ways; increase the orbiter only, increase the booster only, increase the external tank only, or increase both orbiter and booster. An incremental weight is added per specified option, and the configuration is resized.

The fixed hardware option enables the user to fix the entire configuration, thus giving him the capability to investigate changes in payload due to mission changes (polar, resupply, easterly). Additionally, the user can run a single fixed hardware sensitivity without using the entire sensitivity subroutine.





### 3. ORBITER MODULE

The Orbiter Module contains the analytical and empirical weight estimation relationships necessary to completely define the vehicle. These relationships are combined into separate models, each model fully describing a weight group from the NASA functional coding. As an example, the Wing Group Model contains the analytical relationships describing the weight of the torque box plus empirical relationships defining the remaining elements of the wing, such as leading edge, landing gear provision, and elevon. Each model is checked for accuracy at the group level, i.e., the wing model is checked against existing wings (Figure 3.1-5), and again in combination with the remaining models making up the Orbiter Module against an Orbiter point design.

3.0.1 The Orbiter Module is set up to analyze a point design vehicle with minimum data. The NASA weight report and design data, coupled with a three-view drawing of the Orbiter, supplies all inputs necessary to analyze the configuration. Volume III, The Users Manual, lists all required input data, and delineates the interface with the Group Weight Statement and the Design Data Summary. A point design analysis will give a detail line-item comparison with a contractors weight report. This comparison will provide insight to variations of payload and performance characteristics as well as indicate subsystems that require scrutiny, either updating the model to a more realistic level or possible errors in the contractor data.

To run a point design analysis, it is first necessary to determine the performance characteristics, if unknown, from the ESPER program by running a fixed hardware case. In this case, the vehicle module weights, propellant, thrust, and velocity losses are input, and the payload capability is measured for a given mission. Next, an iterative case is run, using the data from the fixed hardware case. The payload, propellants, losses, and vehicle module dry weights are input. The program then analyzes the various subsystems and determines their weight. The growth/uncertainty of each vehicle module is allowed to "float", i.e., vary either up or down to maintain a constant dry weight, therefore physically sizing each system to the point design loads.

3.0.2 The primary purpose of the Orbiter Module is to provide the capability of analyzing an iterated vehicle to determine performance trades and to lend direction to the overall design effort by answering such questions as:

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1. What happens if you vary engine characteristics, such as Orbiter thrust, or specific impulse?
2. Is the staging velocity optimized?
3. What is the minimum gross weight vehicle for the users constraints?
4. What is the effect of changes to the primary construction material?
5. How do geometric changes, such as aspect ratio, payload bay length, or width, effect the configuration?

The inputted parameters start the Orbiter Module iteration for which lift off weight, injected weight, etc., are calculated. These calculated weights, in turn, modify the aerodynamic surfaces; the wing area changes to maintain a constant wing loading and landing speed, and the tail changes to maintain control capability with a constant tail volume coefficient. In turn, these modify the surface controls and the thermal protection system. The auxiliary propulsion system is affected by injected weight and the landing gear by the landing loads. The body is modified by reactions from the above systems which, in turn, changes the inter-stage loads which ripple changes back through the body. The entire module continues the iteration until a completely balanced system exists.

The following sections, 3.1 through 3.6, explain the derivation of each of the primary models making up the Orbiter module.

Section 3.1 Wing and Tail Model

Section 3.2 Body Model

Section 3.3 Thermal Protection System Model

Section 3.4 Landing and Docking Model

Section 3.5 Propulsion System Model

Section 3.6 Remaining System Models

These sections contain the individual model subroutine listings along with a definition of variables. These listings are in FORTRAN V and were written for use on the XEROX SIGMA-7 conversational computer. They are included with the model definitions to facilitate the usage of the individual estimation models for component weight estimation.

3.0.4 Table 3.0-1 is a listing of a typical input file for the Orbiter Module. The definition of the input variables is contained in the program users guide, Volume III, and again in the subsystem models, Sections 3.1 through 3.6. Table 3.0-2 is a typical output of the module and is for the NR 2 December 1972

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TABLE 3.0-1  
ORBITER MODULE DATA FILE

COPY JIMDATA T8 I P(K,NC)

1	2.000	AR1=15.,HYV=100.,TV=155.,H8=110.,L8=235.,L1=747.,NX=.R
2	3.000	NZ=.3,FS=1.4,HF=258.,HL=145.
3	4.000	X=0.0,K1=2.8,SFW=1278.,VC=2912.,PC=14.7,Q=650.,SND=30.6
4	5.000	LNG=77.,FAL=69000.,TMIN=.035,RH8=.1,RH8S=.1
5	6.000	TAUS=22300.,FF=1030000.,IFS=20.,DFLP=1.4,FAB=69000.
6	7.000	RH8B=.1,TAUB=22300.,RH8F=.1,K2=4.,SW=41.,K7=0.,K3=2.,K4=0.
7	8.000	ACD=1744.,FAF=69000.,SAW=809.,FAPR=69000.,TAUPB=22300.
8	9.000	DFAC=1.3,FT=10300000.,RH8TP=.1,RH8PB=.1,K6=120.
9	10.000	NCTPS=4.74,NCA=54.,FWCTPS=1.75,FWDN=1442.,CTTPS=0.0,CTA=0.0
10	11.000	CSTPS=0.0,CSA=0.0,CBTPS=0.0,CBA=7.0,ATTPS=1.22,ATA=1750.
11	12.000	ASTPS=1.22,ASA=1400.,ABTPS=2.97,ABA=2079.,BASTPS=6.6
12	13.000	BASA=371.,TPSCCN=275.,WGTPS=1.895,WGPLE=.059
13	14.000	WIETPS=9.3,TLTPS=1.23,TLPLF=.099,TLETPS=4.61
14	15.000	MCSTPS=0.0,MCSA=0.0,WACCN=2.02,TACCN=2.02,IBA=0.0,IBTPS=0.0
15	16.000	IRC=3476.,LDA=300.,LNTPS=1.0,PR8A=0.0,PR8TPS=0.0,PR8C=1382.
16	17.000	PPC=89.,HYC=77.,SCA=118.,SCTPS=1.0,SWI=4280.,SWC=0.0,WSI=52.
17	18.000	PR88=1.,SPI=0.,HMFAD=1350.,8HFA8=2000.,HULL=37.
18	19.000	BULL=22.,FTU=95000.,RH8=.286,MATL=1,HCLN=20.,OCLEN=20.
19	20.000	HFLN=77.,8FLN=172.,CPIGI=1.
20	21.000	DFNSF=54.7,DFNS8=90.,RH8T=.16,FTUT=135000.,PRES8M=8160.
21	22.000	RH8P=.16,FTUP=135000.,8MSENG=390.,PR8PSY=647.,H8DULF=1071.
22	23.000	PRESF=545.,PRFS8=545.,ACSPR8=7280.,ACSDEN=61.3,ACSPRS=870.
23	24.000	ACSENG=1310.,ACSSYS=300.,ACSM88=910.,8RBMIS=0.0
24	25.000	LGFTU=280000.,LGVEL=150.,LGLC=95.,LGLS=117.,8RCF=315000.
25	26.000	LQDIA=33.,AX2=1068.,AX3=1200.,LNDDKK=0.0
26	27.000	FIXDWT=00.,8UNC1=.1,PER88N=1250.,8RES8=2985.,8RESV=878.
27	28.000	PI8ADU=51612.9,PL8AD8=40000.
28	29.000	FIX8RB=0.0,FIX8WR=0.0
29	30.000	PPWR=3912.,HYDRK=0.0,ELFCK=0.0,SURFK=0.0,AVI8N8=4455.0
30	31.000	ECL88=4093.,PPRAV=1742.,8RIFL=3872.,TABPR8=0.0
31	32.000	8I8NWT=217770.,8L8WT=260731.,8L8WI8=237094.,T8V=470000.
32	33.000	NAENG8=3.0,8MSISP=310.7,8MSDVT=1000.,8MSDVP=950.,8MW=1.65
33	34.000	8TRAP=731
34	34.500	*
35	35.000	AR(1)=2.19,SG(1)=2220.,LAMB(1)=.21,T8CR(1)=.09,T8CT(1)=.12
36	36.000	BCT(1)=17.5,THETA(1)=10.,NZ(1)=3.75,DFLP(1)=296.,LH(1)=0.0
37	37.000	PTBXC(1)=.43,PTBXC(1)=.594,CB(1)=.67,RH8(1)=.10,FA(1)=64394.
38	38.000	CS(1)=.0005,TAU(1)=22320.,TEMP(1)=70.,UWW(1)=0.0,CSR(1)=.67
39	39.000	TMIN(1)=.03,WLF(1)=1.60,WLF(1)=0.0,CLE(1)=.1,AICP=.306,ATLP=1.
40	40.000	EM8DU(1)=1000000.,WC1(1)=0.0,WC2(1)=0.0,CM1(1)=0.0,BLP1(1)=0.0
41	41.000	BLP2(1)=0.0,RCM1(1)=0.0
42	42.000	KEAS=.68,UWAIL=1.75,WB8S=0.,WINGK=0.0,SM8DR=190.
43	43.000	AR(2)=1.44,SG(2)=435.,LAMB(2)=.44,T8CR(2)=.107,T8CT(2)=.09
44	44.000	BCT(2)=0.,THETA(2)=33.,NZ(2)=0.,DFLP(2)=447.,LH(2)=0.
45	45.000	PTBXC(2)=0.,PTBXC(2)=.42,CB(2)=.67,RH8(2)=.1,FA(2)=64394.
46	46.000	CS(2)=.0005,TAU(2)=22320.,TEMP(2)=70.,UWW(2)=0.,CSR(2)=.67
47	47.000	TMIN(2)=.03,WLF(2)=1.6,WLF(2)=0.0,CLE(2)=.1,RDC=.48,URS=1.75
48	48.000	EM8DU(2)=1000000.,WC1(2)=0.0,WC2(2)=0.0,CM1(2)=0.0,BLP1(2)=0.0
49	49.000	BLP2(2)=0.0,RCM1(2)=0.0
50	50.000	RUDUL=3.1,VTV=0.0,LVT=0.0,SPRUD=1.0,TAILK=0.0
51	51.000	*

vehicle easterly mission. The Orbiter Module dry weight is shown as 172,107 lb and compares to the reported weight of 170,000 lb with a variation of 2107 lb, or 1.2 percent. Table 3.0-3 is a detailed listing of the Orbiter Module.

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TABLE 3.0-2  
TYPICAL OUTPUT

UNITED STATES AIR FORCE

WING GROUP (AREA=3220.)		( 18822.)	
BASIC STRUCTURE		13473.	
TORQUE BOX EXPOSE	8822.		
TORQUE BOX CARRY	3876.		
LEADING EDGE	775.		
TRAILING EDGE	0.		
SECONDARY STRUCTURE		1484.	
M.L.G. PROVISIONS	1484.		
CONTROL SURFACE		3864.	
SHELL	1179.		
DRIVE RIB	1628.		
HINGE	284.		
ATTACH	773.		
WING WEIGHT CONSTANT		0.	
TAIL GROUP (AREA= 435.)		( 3721.)	
BASIC STRUCTURE		1725.	
TORQUE BOX	1571.		
LEADING EDGE	153.		
CONTROL SURFACE		1996.	
SHELL	731.		
DRIVE RIB	737.		
HINGE	129.		
ATTACH	399.		
TAIL WEIGHT CONSTANT		0.	
BODY GROUP		( 31189.)	
	FWD	CTR	AFT
BASIC STRUCTURE			
SIDEWALLS	3578.	3341.	1355.
LONGERONS		1065.	408.
FRAMES		1488.	1056.
BULKHEADS		773.	
CREW CPT. PROV.	5124.		
WINDSHIELD PROV.	1656.		
NOSE WHL.WHL PROV	226.		
PAYLOAD REACTION		1200.	
WING SHEAR PROV.		557.	
THRUST STRUCTURE			4003.
TAIL PROV.			158.
SUB TOTAL	10584.	8424.	6991.
SECONDARY STRUCTURE			
CARGO DOOR SHELL		2796.	
CARGO DOOR MECH.		2274.	
MISCELLANEOUS WTS.	0.	0.	120.
TOTAL	10584.	13494.	7111.

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TABLE 3.0-2  
TYPICAL OUTPUT (Continued)

INDUCED ENVIRON. PROT.		( 31041.)
WING		9644.
SURFACE PANELS	7375.	
LEADING EDGE	2269.	
TAIL		1278.
SURFACE PANELS	905.	
LEADING EDGE	373.	
BODY		18153.
BODY PANELS	12125.	
BASE	2277.	
INTERNAL TPS	3476.	
BODY CNST TPS WT.	275.	
WIS CONT. SURFACE		0.
LAND + DOCKING		300.
PROPULSION		1382.
PRIME POWER		89.
HYDRAULICS		77.
SURFACE CONTROLS		118.
LANDING & DOCKING		( 11503.)
NOSE GEAR		1336.
ROLL GEAR	560.	
STRUCTURE	275.	
CONTROLS	501.	
MAIN GEAR		7591.
ROLL GEAR	4020.	
STRUCTURE	2571.	
CONTROLS	1000.	
AUXILIARY SYSTEMS		2576.
DECELERATION SYS	308.	
SEPARATION SYS	1068.	
HANDLING & MANIP	1200.	
MISCELLANEOUS		0.
PROPULSION MAIN ASCENT		( 27114.)
ENGINES+ACCESSORIES		20847.
ENGINES	18880.	
GYRAL SYSTEM	1219.	
CONTROLS	738.	
PROPELLANT UTILIZ	10.	
PROPELLANT SYSTEM		6267.
FILL & DRAIN	773.	
PRESSURIZATION	1095.	
CHILL DUMP LINES	133.	
PRE VALVES	1088.	
FEED SYSTEM	1941.	
DISCONNECTS	488.	
MISCELLANEOUS	749.	
PROPULSION AIR BREATH		( 0.)

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TABLE 3.0-2  
TYPICAL OUTPUT (Continued)

PROPULSION AUXILIARY		( 8166.)
ACS SYSTEM	3963.	
THRUSTERS	1310.	
PROP. SYSTEM	300.	
TANK	1443.	
MODULE	910.	
GAMS SYSTEM	4204.	
THRUSTERS	390.	
PROP. SYSTEM	647.	
TANK	2096.	
MODULE	1071.	
PRIME POWER		( 3912.)
ELECTRICAL		( 4645.)
HYDRAULIC		( 2264.)
SURFACE CONTROLS		( 5511.)
AVIONICS		( 4455.)
ENVIRONMENTAL CONTROL		( 4093.)
PERSONNEL PROVISIONS		( 1742.)
MISCELLANEOUS		( 0.)
GROWTH/UNCERTAINTY		( 13930.)
		- - - - -
DRY WEIGHT		(( 172107.))

GABLER MISSION HISTORY

DRY WEIGHT	( 172107.)
PERSONNEL	1250.
GRS RESV PROP WT.	2955.
PAYLOAD UP	51613.
INERT WEIGHT	( 227955.)
GRS RESV PROP WT.	578.
GRS INFLIGHT LOSSES	3872.
ACS PROP WT	7280.
GAMS PROP WT	23637.
GRS TRAPED PROP WT	1000.
GROSS WT(GRS-ONLY)	( 263744.)
(LAND WT PAY=40000.)	
LANDING WEIGHT	( 217220.)
(INJE WT PAY=51613.)	
INJECTED WEIGHT	( 262744.)

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DETAIL LISTING

18146 FEB 13, 1973 10:123E		
JOB K5511, WHT912		
LIMIT (ORDER), (ACCOUNT), (CR, 9), (TL, 3), (LB, 100), (PS, 200), (TS, 500), (RT, 0)		
PCL		
COPY TK5123 TO LP(K, NC)		
1401 FILE IS BUSY.		
COPY JIM8RB TO LP(K, NC)		
1	1.000	FIXED
2	2.000	C SUBROUTINE GRBMADEI
3	3.000	IMPLICIT REAL (A-Z)
4	4.000	COMMON/MAIN/ PRAPB, PRAPB, BRT, BCANT, ACANT, BCANTY
5	5.000	1, BCANTP, NBENG, NBENG, THBSL, THOSL, THAV, TAV, FL9WR
6	6.000	2, TF, FTW, FIXRD
7	7.000	3, ISPBS, ISPBV, ISPBS, ISPBV, SCD, BTH
8	8.000	4, H, DVCORR, INC, STAGV, DVCORR, DVCNST
9	9.000	5, RFL, THBTC, THBSIT, THBTC, ISPB, ISPB, PRAPBT
10	10.000	6, PRAPB1, PRAPB2, FW(2), DVBNC, DVB, DVT9TC, WRSCD, 01NWT, 01ANWT
11	11.000	7, 91NWT, 01LWT, 01GLOW, 01LOW, TOTAL, S, P, MATCH, TLSSR, FPRP
12	12.000	8, 01HALD, 01LLPLA, 01BLW, 01MSIS, 01MSDVT, 01MSDVP, 01MR
13	13.000	9, LONGP, TAWB, TSWB, SFNS, GRBW, MINGLW
14	14.000	COMMON/ARBA/R1, R2, RL, WTAUX, WTACS, ACSFNG, ACSYS, WTACTK
15	14.040	1, ACSMD, WTMS, 01MSNG, PRAPSY, WT0MTK, MODULE
16	14.080	1, SURFC, PPWR, FLFC, HYDR, AVIARA, ECLSB, PPRBV, BUNCWT
17	14.120	2, ARRMIS, TAPR0, SURFK
18	14.160	1, PERSON, ARFSD, ARFSD, PLBADD, PLBADD, ACSPR0, W0PR0P, SUDLE
19	14.200	2, FIXRB, FIXWR, 01DRWT, 01RFL
20	14.240	1, WWT, WSG, WRSTR, WT0RBF, WT0RBF, LEW, WTE, WAIL, WAS, WADR, WAM
21	14.280	2, WAP, GPRBV, PWINGK, TAIL, TSG, TBSTR, TB0R3B, TLE, WRUD, WRS
22	14.320	3, WRDR, WRH, WRD, PTAILE
23	14.360	1, G37, G1, G2, G3, G4, G7, G8, G9, G10, G11, G12, G15, G16
24	14.400	2, G17, G18, G19, G22, G23, G24, G25, G26, G27, G32, G33, G34
25	14.440	3, G35, G36
26	14.480	1, T0TTPS, TWGWT, WGWT, WGLEWT, TWT, TLEWT, BLBTPS
27	14.520	2, BASEWT, TBWT, PTPSCN, TWT, BTPSWT, MCSWT, LDTWT
28	14.560	3, PRAWT, PPC, PHYC, SCWT
29	14.600	1, TAPR0P, ENGPAC, ENG, TVC, CBNT, PRPUTL, PRBSYS
30	14.640	2, FAD, PRES, CHIL, PREVAL, FEEDS, DISC, MISC
31	14.680	1, LNDK, NG1, NG2, NG3, NGEAR, MG1, MG2, MG3, MGEAR, AX1, AX2
32	14.720	2, AX3, AX3FAR, LNDKK
33	17.000	COMMON/EXT0/BDGRP, TATPS, FWDTK, FAIRT, FWDBLE, FCCTPS
34	18.000	1, CBNSCT, TPCIN, CYLSCT, ACYDM, AFTBLE, WINT, PROSY, AFTNK
35	19.000	2, FEEDSYS, FWDRIA, PRSVNT, AFTCYL, SUMP, AFTBLA, PNPU, TWINT
36	20.000	3, N0SFAR, AVI0NT, UMPPNL, WRETR, TUNNEL, MISC, BAFF, SUBDRY
37	21.000	4, GU, DRYNT, RESIDT, UNDRAN, FEEDTR, PRSURT, FBAS, INERT
38	22.000	5, GRASSW, TLAMP, 01TRAP, FXTL, FXTD, BLKHD, FXTB, EXTHH, SIMPTK
39	23.000	COMMON/STRO/ABT, HTV, LTV, HB, LB, LI, NX, NZ, FS
40	24.000	1, HF, HL, X, K1, CFW, VC, PC, Q, SNO, LING
41	25.000	2, FAL, TMIN, RH0L, RH0S, TAUS, FF, LFS, DELP, FAB, RH0B
42	26.000	3, TAUB, RH0F, K0, SW, K7, K3, K4, ACD, FAF, SAW, FAPB, TAUPB
43	27.000	4, DFAC, ET, RH0TP, RH0PB, K6
44	28.000	COMMON/THERD/NCTPS, NCA, FWTTPS, FWDAT, CTTPS, CTA, CSTPS
45	29.000	2, CSA, CBTPS, CRA, ATTPS, ATA, ASTPS, ASA, ABTPS, ABA, BASTPS
46	30.000	3, BASA, TPSCAN, WGTTPS, WGLE, WLETPS, TLTPS, TLPLE
47	31.000	4, TLETPS, MCSTPS, MCSA, WACON, TACON, IRA, IBTPS, IBC, LDA, LDTPS
48	32.000	5, PRAA, PRATPS, PRAC, PPC, HYC, SCA, SCTPS, SWI, SWC, WSI
49	33.000	COMMON/ASPD/P0G0, SPI, HHEAD, RHEAD, HULL, BULL, FTU, RH0
50	34.000	1, MATL, HOLEN, ACLEN, HELEN, 01LEN, CPLGI
51	34.200	COMMON/LDGD/GFTU, LGVSL, LGLC, LGLS, LGDIA, BRCF
52	35.000	NAMFLIST ARI, HTV, LTV, HB, LB, LI, NX, NZ, FS

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53	36.000	1, HFL, HL, XK1, GF, WVC, PC, Q, SNO, LNG
54	37.000	3, FAL, TMIN, RHAL, RHOS, TAUS, FF, LFS, DELP, FAB, RHOB
55	38.000	4, TALB, RHAF, K2, SW, K7, K3, K4, ACD, FAF, SAW, FAPB, TAUPB
56	39.000	5, DFAC, ET, RHOT, RHOPB, K6
57	40.000	6, NCTPS, NCA, FWDTPS, FWD, CTTPS, CTA, CSTPS, CSA, CBTPS
58	41.000	7, CBA, ATTPS, ATA, ASTPS, ASA, ARTPS, ABA, RASTPS, BASA, TPSCBN
59	42.000	8, NGTPS, WGLE, WLFTPS, TLTPS, TLPLE, TLETPS
60	43.000	8, MCSTPS, MCSA, WACBN, TACBN, TRA, IBTPS, IBC, LDA, LDTPS, PRBA
61	44.000	9, PRATPS, PRAC, PRC, HVC, SCA, SCTPS, SWI, SWC, WSI
62	45.000	4, PRSR, SP, HHEAD, BHEAD, HULL, BULL, FTU, RHB, MATL, HCLFN, BCLEN
63	46.000	5, HFLFN, RFLFN, CPLGI
64	47.000	1, DENSE, DENSE, RHAT, FTUT
65	48.000	1, PRESB, RHAP, FTUP, BMSENG, PRAPSY, MDUIE, PRESF, PRESB
66	49.000	2, ACSPRB, ACSDFB, ACSPRS, ACSFNG, ACSYS, ACSMD
67	50.000	3, BRARMIS, FIXDWT, GUNC1, PERSON, BRESO, BRFSV, PLBADD, PLBADD
68	51.000	4, FIXARB, FIXVAR, PPWR, HYDRK, ELECK, AVIANG, FCLSA
69	51.200	5, PPRAV, BRIFL, TABPR, SURFK, ALLPL, WBRBP
70	51.400	6, LGFTU, LGVL, LGI, GLS, LGDJA, BRCF, AX2, AX3, LNDOKK
71	51.600	7, BLANWT, BLAWT, BLBWT, TBV, NPFNGB, BMSISP, BMSDVT
72	51.800	8, BMSDVP, BMR, ATRAP
73	53.000	INPUT(1)
74	54.000	IF (FIXVAR, GT, 0.0, BR, FIXARB, GT, 0.0) GO TO 400
75	54.020	LDB=0
76	54.040	LHG=1 GLC
77	55.000	CALL AERB(WSG, WRCT, WTHETA, WNZ, WB, SAIL, SRUD, VB, PV, WESG
78	55.200	1, TSG, SURFI, LDB, LHG
79	55.400	2, WWT, WBTTR, WTBRE, WTBRC, LEW, WTE, WAIL, WAS, WADR, WAH, WAP
80	55.600	3, PWINGK, GPRAV
81	55.800	1, TAIL, TRSTR, TTARGB, TLE, WRUD, WRS, WRDR, WRH, WRP, PTAILK
82	56.000	CALL STRUCT(VB, WBCT, WTHETA, WNZ, WB, SAIL, SRUD, PV, R1, R2, RL
83	56.200	1, G17, G1, G2, G3, G4, G7, G8, G9, G10, G11, G12, G15, G16
84	56.400	2, G17, G18, G19, G22, G23, G24, G25, G26, G27, G32, G33, G34
85	56.600	3, G35, G36
86	57.000	CALL THERM(WSG, WESG, TSG, TRTPS, TWGWT, WSWT, WGLEWT, TWT, TLEWT
87	57.200	1, RLBTPS, PASEWT, IBTWT, PTPSCN, TTWT, BTPSWT, MCSWT, LDTWT
88	57.400	2, PRAT, PRPC, PHYC, SCWT
89	58.000	CALL ASCENT(TAPRP, ENGPAC, FNG, TVC, CNTR, PRPUTL
90	59.000	1, PRACS, FAD, PRES, CHIL, PREVAL, FEEDS, DISC, MISC
91	59.200	CALL LABSYS(LNDOKK, NG1, NG2, NG3, NGEAR, MG1, MG2, MG3
92	59.400	1, MGEAR, AX1, AX2, AX3, AXGEAR, LNDOKK
93	59.500	K=1.0
94	59.600	IF (SURFI, GT, 0.0) K=3.0
95	60.000	SURFC=1.0AC.+2.45*SAIL+K*(360.+1.67*SRUD)+SURFK
96	60.020	PPWR=PPWR
97	60.040	HYDR=224.4*((WSG+K*TSG)/4525.)*HYDRK
98	60.060	ELECK=ELECK+2.05.*1840.*(LI-X)/747.
99	60.080	AVIANG=AVIANG
100	60.100	ECLSA=ECLSA
101	60.120	PPRAV=PPRAV
102	60.140	TAPRP=TAPRA
103	61.000	C
104	62.000	C BMS SYSTEM CALCULATIONS
105	63.000	C
106	64.000	WTPRP=RLBWL*(EXP(BMSDVT/(32.174*BMSISP))-1.)
107	65.000	WBRBP=RLBWL*(EXP(BMSDVP/(32.174*BMSISP))-1.)
108	66.000	WFUEL=WTPRP/(1.+BMR)
109	67.000	WAX=BMR*WFUEL
110	68.000	VFUEL=(WFUEL/DENSE)*1.15
111	69.000	VAX=(WAX/DENSE)*1.15
112	70.000	FTANK=3./2.*RHOT*PRESB/FTUT*VAX*1728.*1.28
113	71.000	BTANK=3./2.*RHOT*PRESB/FTUT*VAX*1728.*1.28



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114	72.000	VPRFS=(PRESB*VOX+PRESF*VFUFL)/PRESBM*1.47
115	73.000	PRESTK=3./2.*RHQP*PRESBM*VPRFS/FTUP*172R.*1.2R
116	74.000	WTBMTK=FTANK*BTANK*PRESTK
117	75.000	WTBMS=WTBMTK*BMSENG*PRBPSY*MBDULE
118	76.000	C ACS SYSTEM CALCULATIONS
119	77.000	ACSVBL=ACSPRA/ACSDFN*1.15
120	78.000	ACSTNK=3./2.*RHQT*ACSPRS*ACSVBL/FTUT*172R.*1.2R
121	79.000	VPTNK=ACSVBL*ACSPRS/PRESBM*1.47
122	80.000	PTNK=3./2.*RHQT*PRESBM*VPTNK/FTUP*172R.*1.2R
123	81.000	WTACTK=(ACSTNK*PTNK)*1.25
124	82.000	WTACS=WTACTK*ACSSYS*ACSENG*ACSM6D
125	83.000	WTAUX=WTBMS+WTACS
126	84.000	BRBMIS=BRBMIS
127	85.000	SUDRY=WT+TAIL*G37+TBTTPS+SURFC+TAPRSP+WTAUX+BRBMIS
128	85.500	1+PPWR*HYDR*FIEC*AVI9NS+ECLSR*PPR9V*LNDDK*TABPR8
129	86.000	SUDLF=SUDRY*ENG
130	87.000	IF(FIXDWT.GT.0.0) BUNCWT=FIXDWT-SUDRY
131	88.000	IF(FIXDWT.GT.0.0) G8 TO 50
132	89.000	BUNCWT=SUDLF*BUNC1
133	90.000	50 BDRYWT=SUDRY+BUNCWT
134	91.000	BINWT=BDRYWT*PERSBN*ARES0+PL8ADU
135	92.000	BLANWT=BINWT*PL8ADU+PL8ADD*GRESV
136	93.000	BINJWT=BLANWT*ACSPR9+W8PR9*GRESV*PL8ADD+PL8ADU*8R1FL
137	94.000	IF(S.EQ.0.0) BTRAP=1000
138	95.000	BL8WT=BINJWT*BTRAP
139	96.000	BL8WLB=BL8WT*W8PR9P
140	97.000	BL8LPI8=BL8WT*W8PR9P*PL8ADU
141	98.000	G8 TO 500
142	99.000	400 BL8PL8=BL8PL8
143	99.020	W8PR9P=W8PR9P
144	99.040	PL8ADU=PL8ADU
145	99.060	BL8WT=BL8PL8*PL8ADU+W8PR9P
146	100.000	500 CALL OUTPUT
147	101.000	STOP
148	102.000	END
149	103.000	SUBROUTINE AFR8(WSG,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,VB
150	104.000	1,PV,WES3,TSG,SURF1,LDG,LHG
151	104.200	2,WWT,WBSTR,WTORBE,WTORBC,LEW,WTE,WAIL,WAS,WADR,WAH,WAP
152	104.400	3,PWTXGK,GPR9V
153	104.600	1,TAIL,TBSTR,TBQGB,TLE,WRUD,WRS,WRDR,WRH,WRP,PTAILK1
154	104.800	REAL LAMB,LH,M,K,NZ,LE,KFAS,LAMB,MP,KP,LEW
155	104.900	1,KMPP,KMC,MPP,LDG,LHG
156	105.000	DIMENSION AR(2),SG(2),LAMB(2),TBCT(2)
157	106.000	1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
158	107.000	2,PTBXC(2),CR(2),RHQ(2),FA(2),CS(2),TAU(2),TFMP(2)
159	108.000	3,UWW(2),CSR(2),TMIN(2),ULE(2),WLE(2),CLE(2)
160	108.500	4,FMBDU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
161	110.000	COMMON/RWRC/ AR,SG,LAMB,TBCT,TBCT,THETA,NZ,DELP,LH
162	111.000	1,PTBXC,PTBXC,CR,RHQ,FA,CS,TAU,TFMP,UWW,B,SEXP,SL,RBM
163	111.500	3,FMBDU,WKPK9,WREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
164	112.000	2,WLF,ULE,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLF
165	113.000	COMMON/RWRW/KEAS,AIIP,AICP,UWAIL,WWS,WINCK,TLDG,SMGDR,TLMG
166	114.000	COMMON/RWRVT/RDC,RDDUL,URS,VTVCLVT,SPRUD,TAILK
167	115.000	COMMON/MAIN/ PR9PB,PR9PB,BBT,BCANT,BCANT,BCANTY
168	116.000	1,BCANTP,N9ENG8,N9ENG8,TH8SL,TH8SL,TH8V,T8V,FLWR
169	117.000	2,TF,FTW,FXHRD
170	118.000	3,ISPBS,ISPRV,ISPBS,ISPRV,SCD,BTW
171	119.000	4,H,DVC9PR,INC,STAGV,DVCON,DVCONST
172	120.000	5,RFL,THATC,TH8SLT,THATC,ISPA,ISPB,PR9BT
173	121.000	6,PR9P1,PR9P2,FW(2),DV8NC,DVB,DVT8TC,W8SCD,BINWT,BLANWT
174	122.000	7,BINJWT,BL8WT,8GLEW,8GLEW,T8TAL,S,P,MATCH,TLSSR,FPRP

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175	123.000	8, BHALD, ALLPLA, BLOWLB, BMSISP, BMSDVT, BMSDVP, BMR
176	124.000	9, LANGP, TQWB, TQWB, SFNS, GRBW, MINGLW
177	125.000	NAMFLIST
178	126.000	1, AR, SG, LAMB, TBCR, TBCT, BCT, THETA, NZ, DELP, LH, PTBXC
179	127.000	2, PTRXE, CR, RHA, FA, CS, TAU, TEMP, UWW, CSR, TMIN
180	128.000	3, ULF, KEAS, AICP, UWAIL, CLE, AILP
181	129.000	4, RDC, RUUDL, URS, WLE
182	130.000	5, WWS, VTVC, LVT, SPRUD, WINGK, TAILK
183	130.500	6, FMRDU, WC1, WC2, CM1, BLP1, BLP2, BCM1, SMGDR
184	130.520	TLDQ=LDQ
185	130.540	TLMG=LMG
186	132.000	INPUT(1)
187	133.000	CALL WING(WSG, WBCT, J, BLANWT, SAIL, LEW, WAS, WADR, WAH, WAP, WAIL
188	134.000	1, WTF, WWT, WBSTR, GPRV)
189	135.000	WZ=NZ(J)
190	136.000	WB=B
191	137.000	WTHETA=THETA(J)
192	138.000	WSG=SG(J)
193	139.000	WBCT=BCT(J)
194	139.200	WFSG=SEXP
195	139.400	WTBRE=WANS(20)
196	139.600	WTBRE=WANS(21)
197	139.800	PWINGK=WINGK
198	140.000	CALL VTAIL(J, BLANWT, WSG, WB, SRUD, TLE, WRS, WRDR, WRH
199	141.000	1, WRP, TAIL, VB, P, TBSTR, WRUD)
200	142.000	VB=B
201	142.200	PV=CI
202	142.400	TSG=SG(J)
203	142.600	SURF1=SPRUD
204	142.800	TTBRE=TANS(22)
205	142.900	PTAILK=TAILK
206	143.000	RETURN
207	144.000	END
208	145.000	SUBROUTINE WING(WSG, WBCT, J, BLANWT, SAIL, LEW, WAS, WADR, WAH, WAP
209	146.000	1, WAIL, WTF, WWT, WBSTR, GPRV)
210	146.200	REAL LAMB, H, M, K, NZ, LF, KFAS, LAMB, MP, KP, LEW
211	146.400	1, KMPP, KMC, MPP, LDG, LMG
212	147.000	DIMENSION AR(2), SG(2), LAMB(2), TBCR(2), TBCT(2)
213	148.000	1, BCT(2), THETA(2), NZ(2), DELP(2), LH(2), PTBXC(2)
214	149.000	2, PTRXE(2), CR(2), RHA(2), FA(2), CS(2), TAU(2), TEMP(2)
215	150.000	3, UWW(2), CSR(2), TMIN(2), ULF(2), WLE(2), CLE(2)
216	150.500	4, FMRDU(2), WC1(2), WC2(2), CM1(2), BLP1(2), BLP2(2), BCM1(2)
217	152.000	COMMON/RWRC/ AR, SG, LAMB, TBCR, TBCT, BCT, THETA, NZ, DELP, LH
218	153.000	1, PTRXC, PTBXC, CR, RHA, FA, CS, TAU, TEMP, UWW, B, SEXP, SL, RBM
219	153.500	3, FMRDU, WSWPKR, WREI, WC1, WC2, CM1, BLP1, BLP2, BCM1
220	154.000	2, WLE, ULF, CSR, TMIN, WANS(22), TANS(22), SL1, SL2, CLF
221	155.000	COMMON/RWRW/ KEAS, AILP, AICP, UWAIL, WWS, WINGK, TLDQ, SMGDR, TLMG
222	156.000	J=1
223	157.000	IF (WWS.GT.0.0) SG(J)=BLANWT/WWS
224	158.000	CALL TROBX(J, BLANWT)
225	158.200	LDQ=TLDQ
226	158.400	LMG=TLMG
227	159.000	BSC=BCT(J)/B
228	160.000	CR=(2.*SG(J))/(R*(1.+LAMB(J)))
229	161.000	BF=B-BCT(J)
230	162.000	STBF=PTRXE(J)*SEXP
231	163.000	CF=CR*(1.-BSC*(1.-LAMB(J)))
232	164.000	CRCF=CR/CF
233	165.000	SAIL=AILP*BF*AICP*CF/2.*(2.*(1.-LAMB(J))*CRCF*(1.-BSC)*(AILP))
234	166.000	CRST=COS(THETA(J)/57.2958)
235	167.000	CR=(2.*SAIL)/(BF*(1.+LAMB(J)))

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236	168.000	CT=CR*LAMB(J)
237	169.000	TR=CR*TACR(J)
238	170.000	TT=CT*TACT(J)
239	171.000	CMR=(CR+CT)/2.
240	172.000	SRUD=SA*TL
241	173.000	RHM=SRUD*144.*KFAS*12.*CMR*.5*.001
242	174.000	HLTR=12.*(TR+TT)/2.
243	175.000	HLLR=BE/COST
244	176.000	WAS=UWATL*SA*TL
245	177.000	WADR=(CMR*(RHM/HLTR))**.75)*2.
246	178.000	WAH=(.40*HLLR*RHM**2)*2.
247	179.000	WAP=.25*(WAS+WADR+WAH)
248	180.000	WATL=WAS+WADR+WAH+WAP
249	181.000	SLF=CLE(J)*SEXP
250	181.200	WLET=2.2*SLF+WLF(J)
251	182.000	LEW=WLET*ULE(J)
252	182.200	F4G=BLANWT*350000./215115.
253	182.400	GPRBV=.42*LDG**3*SMGDR+.077*(.001*FMG*LMG)**.9
254	183.000	STF=SEXP*STF*SA*TL*SLF
255	184.000	WTE=1.87*STF*(.001*BLANWT*NZ(J)/SG(J))**.2
256	185.000	IF(SI 2.GT.SL1) WTE=1.87*STF*(.001*DELP(J))**.2
257	186.000	WWT=WANS(22)+LEW+WATL+WTE+WINGK+GPRBV
258	186.500	WBSTR=WANS(20)+WANS(21)+LEW+WTE
259	187.000	RETURN
260	188.000	END
261	189.000	SUBROUTINE VTAIL(J,BLANWT,WSG,WB,SRUD,TLF,WRS,WRDR
262	190.000	1,WRH,WRP,TAL,VR,P,TBSTR,WRUD)
263	190.200	REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMBP,MR,KP,LEW
264	190.300	1,KMPP,KMC,MPP,LQG,IMG
265	191.000	DIMENSION AR(2),SG(2),LAMB(2),TBCT(2)
266	192.000	1,BCT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
267	193.000	2,PTBXC(2),CB(2),RHA(2),FA(2),CS(2),TAU(2),TEMP(2)
268	194.000	3,UWV(2),CSR(2),TMIN(2),ULF(2),WLF(2),CLE(2)
269	194.500	4,FMQDU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
270	196.000	COMMON/RWRC/ AR,SG,LAMB,TACR,TBCT,BCT,THETA,NZ,DELP,LH
271	197.000	1,PTBXC,PTBXC,CB,RHA,FA,CS,TAU,TEMP,UWV,B,SEXP,SL,RBM
272	197.500	3,FMQDU,WSWPKR,WRREI,WC1,WC2,CM1,BLP1,BLP2,BCM1
273	198.000	2,WLF,ULF,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLE
274	199.000	COMMON/RWRVT/RDC,RUDUL,URS,VTVC,LVT,SPUD,TAILK
275	200.000	J=2
276	201.000	IF(VTVC.GT.0.0) SG(J)=(WSG*WR*VTVC)/VT
277	202.000	CALL TRPBX(J,BLANWT)
278	203.000	COST=COS(THETA(J)/57.2958)
279	204.000	CR=(2**SG(J))/(B*(1.+LAMB(J)))
280	205.000	CT=CR*LAMB(J)
281	206.000	IF(SPRUD.GT.0.0.AND.P.GT.0.0) GB TB 5
282	207.000	IF(SPRUD.GT.0.0) TACR(J)=TACR(J)*.5
283	208.000	IF(SPRUD.GT.0.0) TACT(J)=TACT(J)*.5
284	209.000	TR=CR*TACR(J)
285	210.000	TT=CT*TACT(J)
286	211.000	BF=B*BCT(J)
287	212.000	CMR=RDC*(CR+CT)/2.
288	213.000	SRUD=RDC*SG(J)
289	214.000	RHM=SRUD*144.*RUDUI*12.*CMR*.5*.001
290	215.000	HLTR=12.*(TR+TT)/2.
291	216.000	HLLR=BF/COST
292	217.000	WRS=URS*SRUD
293	218.000	WRDR=.44*CMR*(RHM/HLTR)**.75
294	219.000	WRH=.40*HLLR*RHM**2
295	220.000	IF(SPRUD.EQ.0.0) GB TB 10
296	221.000	WRS=WRS*2.

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297	222.000	WRDR=WRDR*2.
298	223.000	WRH=WRH*2.
299	224.000	10 WRP=.25*(WRS+WRDR+WRH)
300	224.100	WRUD=WRG+WRDR+WRH+WRP
301	224.200	WLET=2.2*CLE(J)*SG(J)+WLF(J)
302	225.000	TLE=ULE(J)+WLET
303	226.000	TATL=TANS(22)+WRUD+TLE+TATLK
304	226.500	TASTR=TANS(22)+TLE
305	227.000	RETURN
306	228.000	END
307	229.000	SUBROUTINE T30BAX(J,ALANWT)
308	229.200	REAL LAMP,LH,M,K,NZ,LE,KEAS,LAMPB,MP,KP,LEW
309	229.300	1,KMPP,KYC,MPP,LQ,LMG
310	230.000	DIMENSION G(22)
311	231.000	DIMENSION AR(2),SG(2),LAMB(2),TBCR(2),T8CT(2)
312	232.000	1,ACT(2),THETA(2),NZ(2),DELP(2),LH(2),PTBXC(2)
313	233.000	2,PTRXE(2),CB(2),RHO(2),FA(2),CS(2),TAU(2),TEMP(2)
314	234.000	3,UWW(2),CSR(2),TMIN(2),ULF(2),WLE(2),CLE(2)
315	234.500	4,FMDU(2),WC1(2),WC2(2),CM1(2),BLP1(2),BLP2(2),BCM1(2)
316	234.600	COMMON/RWRC/ AR,SG,LAMB,TBCR,T8CT,BCT,THETA,NZ,DELP,LH
317	237.000	1,PTBXC,PTBXC,CB,RHO,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
318	237.500	3,FMDU,WSWPKR,WREI,WC1,WC2,CM1,BLP1,BLP2,BCM1
319	238.000	2,WLF,ULF,CSR,TMIN,WANS(22),TANS(22),SL1,SL2,CLE
320	239.000	CRST=CRS(THETA(J)/57.2958)
321	240.000	H=(AR(J)*SG(J))*5
322	241.000	CR=(2*SG(J))/(R*(1.+LAMB(J)))
323	242.000	CT=CR*LAMB(J)
324	243.000	CF=CR*(1.-(1.-LAMB(J))*BCT(J)/B)
325	244.000	TR=TACR(J)*12.*CR
326	245.000	TT=TACT(J)*12.*CT
327	246.000	IF(LAMB(J).EQ.0.) TT=T8CT(J)
328	247.000	M=TT/TR
329	248.000	TF=TR*(1.+(M-1.)*BCT(J)/B)
330	249.000	MP=TT/TF
331	249.100	RBSPC=TF*(1.8+.2*MP)
332	249.200	IF(RBSPC.LT.12.) RBSPC=12.
333	250.000	IF(MP.GT..99) MP=.99
334	251.000	LAMPB=LAMB(J)/(1.-(1.-LAMB(J))*BCT(J)/B)
335	252.000	KP=.2*(1.+LAMPB)/(1.+LAMPB)*((1.-3.*MP)*(1.-MP)+2.*MP**2*ALOG(MP))
336	253.000	KP=KP/(1.-MP)**2
337	254.000	KP=KP*(1.-LAMPB)/(1.+LAMPB)*((2.-7.*MP+11.*MP**2)
338	255.000	*((1.-MP)+6.*MP**3*ALOG(MP))/3/(1.-MP)**4
339	256.000	SCT=BCT(J)*(CR+CF)/2.
340	257.000	SFXP=SG(J)*SCT
341	258.000	STBC=PTBXC(J)*SCT
342	259.000	STBF=PTBXC(J)*SFXP
343	260.000	WW=UWW(J)*SG(J)
344	260.020	BF=R*BCT(J)
345	260.040	TANT=SIN(THETA(J)/57.2958)/CRST
346	260.060	TANLE=TANT+2.*(1.-LAMB(J))/(AR(J)*(1.+LAMB(J)))
347	260.080	TANTE=TANLE+4.*(1.-LAMB(J))/(AR(J)*(1.+LAMB(J)))
348	260.100	ANGLE=57.2958*ATAN(TANLE)
349	260.120	ETAWNG=(.04+AR(J)*(.0049+.000045*ANGLE))*LAMB(J)
350	260.140	ETAWNG=ETAWNG+.05*(LAMB(J)-.4)**2
351	260.160	ETAWNG=ETAWNG+.41*(1.+0.0033*ANGLE)-(60.-ANGLE)/3000.
352	260.180	F=3.395+.5*ETAWNG
353	260.200	GFE=AR(J)*TANTE*(.01484)
354	260.220	H=(AR(J)-4.)*(1.+3.5*TANTE)*.003
355	260.240	IF(AR(J).LT.4.) H=0.0
356	260.260	CBARCL=F+GFE+H
357	260.280	ETAF=BCT(J)/R

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358	260.300	FF=F*(1.-ETAF**2)**.5*(20.*FTAWNG-8.4RR)*ETAF**2
359	260.320	1*(1.-ETAF**2)**.5
360	260.340	GFFF=GFF*(1.-.466*ETAF+7.314*ETAF**2)*(1.-ETAF**2)**.5
361	260.360	HF=H*(1.-14.5*ETAF**2+21.*ETAF**4)*(1.-ETAF**2)**.5
362	260.380	CBARF=FF+GFFF+HF
363	260.400	SLRATI=(CBARCL+CBARF)*ETAF/2.
364	260.420	ETAFXP=(FTAWNG-SLRATI)*ETAF*.5*(1.-SLRATI)*ETAF)
365	260.440	1/(1.-SLRATI)
366	260.460	ETAFXP=ETAFXP*R/BE
367	260.480	ETAUNF=(2.*LAMB+1.)/(3.*(LAMB+1.))
368	260.500	RLCP=ETAFXP/ETAUNF
369	260.520	SLTOT=((BLANWT*.5*WW)*NZ(J)+H(J))
370	260.540	SL1=SLTOT*(1.-SLRATI)
371	260.560	SL2=RLCP(J)*CEXP
372	263.000	SL=SL1
373	264.000	IF (SL2.GT.SI1) SL=SL2
374	266.000	RBM=RLCP*(SL/6.)*BF/(2.*CAST)*(2.*LAMB+1.)/(LAMB+1.)
375	267.000	IF (J.F2.2) RBM=4.*RBM
376	267.020	TCB=CH(J)*RBM/20.
377	267.040	PF=RBM/(TF*CF*PTBXF(J)*.R)
378	267.060	TCBVF=TCB/(RHS(J)*144.)*PF/FA(J)
379	267.080	RRNN=2.*PF**2*RRSPC/(EMBDU(J)*TCBVF*TF*.A)
380	267.100	TRIBF=TCB/(RHS(J)*144.)*RRNN/FA(J)
381	267.120	TRSTF=.7.5*RRM*12./(2.1414**2*EMBDU(J)*PTBXF(J)*CF*12.*RRSPC)
382	267.140	IF (TRSTF.GT.TRIBF) TRIBF=TRSTF
383	267.160	TRIBT=TCB/(RHS(J)*144.)*
384	267.180	WRIBF=RHS(J)*TRIBF*TF*CF*PTBXF(J)*12.
385	267.200	WRIBT=RHS(J)*TRIBT*TF*CT*PTBXF(J)*12.
386	267.220	WSWPKR=.058*(ABS(SL-.001*SIN(THETA(J)/57.2958)*BF/
387	267.240	1(COST*TF/1.2))**.92
388	268.000	G(1)=2.*CB(J)*STBE
389	269.000	G(2)=2.*CB(J)*STBC
390	270.000	G(3)=RHS(J)*KPC*RE*RRM*(1.+LAMB)/(FA(J)*.8*TF*(2.*LAMB+1.))*144.
391	271.000	G(4)=RHS(J)*RRM*2.*CAST*BCT(J)*144./(FA(J)*.8*TF)
392	272.000	TC=TR*(1.-.1.*M)*BIP1(J)*2./BE)
393	272.020	MPP=TC/TF
394	272.040	KMPP=2.*(1./(1.-MPP)+MPP*ALAG(MPP)/(1.-MPP)**2)
395	272.060	KMC=ALAG(MPP)/(MPP-1.)
396	272.070	BL1=(BLP1(J)-RCT(J)/2.)/CAST
397	272.080	WREL1=RHS(J)*WC1(J)*NZ(J)*BL1**2*144.*KMPP/(FA(J)*.8*TF)
398	272.100	WREL1=WREL1+RHS(J)*WC1(J)*NZ(J)*BL1*144.*COST*BCT(J)/
399	272.120	1(FA(J)*.8*TF)
400	272.140	WREL1=WREL1+RHS(J)*WC1(J)*NZ(J)*BL1*12./TAU(J)
401	272.160	TC=TR*(1.-.1.*M)*BIP2(J)*2./BE)
402	272.180	MPP=TC/TF
403	272.200	KMPP=2.*(1./(1.-MPP)+MPP*ALAG(MPP)/(1.-MPP)**2)
404	272.210	BL2=(BLP2(J)-RCT(J)/2.)/CAST
405	272.220	WREL2=RHS(J)*WC2(J)*NZ(J)*BL2**2*144.*KMPP/(FA(J)*.8*TF)
406	272.240	WREL2=WREL2+RHS(J)*WC2(J)*NZ(J)*BL2*144.*COST*BCT(J)/
407	272.260	1(FA(J)*.8*TF)
408	272.280	WREL2=WREL2+RHS(J)*WC2(J)*NZ(J)*BL2*12./TAU(J)
409	272.300	KCM=4.*RHS(J)*CM1(J)*BCM1(J)*144.*KMC/(FA(J)*.8*TF)
410	272.320	WREFL=(WREL1+WREL2+WCM)
411	272.340	G(5)=12.*RHS(J)*BE/CAST*(2.*CS(J)*(1.*TF*(1.+MP)/2.))**2
412	272.360	1+TM1N(J)*(1.*TF*(1.-MP)))
413	272.380	G(6)=2.*CH(J)*.8*TF*RCT(J)/12.
414	272.400	G(7)=2.*RHS(J)*RBM*12./TAU(J)
415	272.420	IF (J.EQ.2) G(7)=G(7)*.5
416	272.440	G(8)=(WRIBF+WRIBT)/(2.*RRSPC*COST)*BE*12.
417	272.480	G(9)=WRIBF/(RRSPC)*RCT(J)*12.
418	279.000	G(10)=(G(1)+G(3)+G(5)+G(7)+G(8))*0.1

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419 • 280.000 G(11)=G(2)+G(4)+G(6)+G(9)*.01
420 • 281.000 G(12)=.14*STBE
421 • 282.000 G(13)=.14*STBC
422 • 283.000 G(14)=.10*G(2)+.20*(G(7)+G(8))
423 • 284.000 G(15)=.10*G(4)+G(9)*.2
424 • 285.000 G(16)=G(1)+G(3)+G(5)+G(7)+G(8)+G(10)+G(12)+G(14)
425 • 285.500 1+NSWPKR+WBRFI
426 • 286.000 G(17)=G(2)+G(4)+G(6)+G(9)+G(11)+G(13)+G(15)
427 • 287.000 G(18)=.25*G(16)
428 • 288.000 G(19)=.25*G(17)
429 • 289.000 G(20)=G(16)+G(18)
430 • 290.000 G(21)=G(17)+G(19)
431 • 291.000 G(22)=G(20)+G(21)
432 • 292.000 DB 200 IK=1,22
433 • 293.000 IF(J.EQ.1) WANS(IK)=G(IK)
434 • 294.000 IF(J.EQ.2) TANS(IK)=G(IK)
435 • 295.000 200 CONTINUE
436 • 296.000 RETURN
437 • 297.000 END
438 • 298.000 SUBROUTINE STRUCT (VB,WBCT,WTHETA,WNZ,WB,SAIL,SRUD,PV
439 • 299.000 1,R1,R2,RL,G37,G1,G2,G3,G4,G7,G8,G9,G10,G11,G12,G15,G16
440 • 299.200 2,G17,G18,G19,G22,G23,G24,G25,G26,G27,G32,G33,G34
441 • 299.400 3,G35,G36)
442 • 300.000 IMPLICIT REAL (A-Z)
443 • 301.000 COMMON/MAIN/ PRAPB,PRAPB,BBT,BCANT,BCANT,BCANTY
444 • 302.000 1,SCANTP,NBENG8,NBENG8,THBSL,THBSL,THBV,TBV,FL9WR
445 • 303.000 2,TF,FTW,FXHRD
446 • 304.000 3,ISPPS,ISPV,ISPBBS,ISPBVS,SCD,BTW
447 • 305.000 4,H,DVCBR,INC,STAGV,DVCBN,DVCNST
448 • 306.000 5,RFL,THATC,THBSLT,THATC,ISPA,ISPB,PRAPBT
449 • 307.000 6,PRAPB1,PRAPB2,FW(2),DV8NC,DVB,DVT8TC,W8SCD,B1NWT,BLANWT
450 • 308.000 7,B1NWT,PLAWT,BGL8W,GL8W,T8TAL,S,P,MATCH,TLSSR,FPRP
451 • 309.000 8,PHLD,ALLPLA,B18WL8,BMSISP,BMSDVT,BMSDVP,BMR
452 • 310.000 9,LANGP,T8W8,T8W8,SENS,G8W8,MINGLW
453 • 311.000 COMMON/STRO/
454 • 312.000 1,AB1,HTV,LTV,H8,L8,L1,NX,NZ,FS
455 • 313.000 2,HF,HL,X
456 • 314.000 3,K1,SFW,VC,PC,Q,SND,ING
457 • 315.000 4,FAL,TMIN,RH8L,RH8S,TAUS
458 • 316.000 5,FF,LFS,DELP,FAB,RH8B,TAUB
459 • 317.000 6,RH8F,K2,SW,K7
460 • 318.000 7,K3,K4,ACD,FAF
461 • 319.000 8,SAW,FAPB,TAUPB
462 • 320.000 9,DFAC,ET,RH8TP,RH8PB
463 • 321.000 K,K6
464 • 322.000 C MOMENT CALCULATIONS DUE TO INTERSTAGE REACTIONS
465 • 323.000 SMAR1=(FS*BLAWT*NX*H8)+(BLAWT*NZ*(L1-L8)*FS)
466 • 324.000 1=(FS*T8V*NBENG8*C8S(AB1/57.2958)*HTV)
467 • 325.000 2+(FS*T8V*NBENG8*SIN(AB1/57.2958)*(L1+LTV))
468 • 326.000 SMAR2=(FS*T8V*NBENG8*C8S(AB1/57.2958)*HTV)
469 • 327.000 1-(T8V*NBENG8*SIN(AB1/57.2958)*LTV*FS)
470 • 328.000 2-(BLAWT*NX*H8*FS)+(BLAWT*NZ*L8*FS)
471 • 329.000 R2=SMAR1/L1
472 • 330.000 R1=SMAR2/L1
473 • 331.000 RL=T8V*NBENG8*FS*C8S(AB1/57.2958)-BLAWT*NX*FS
474 • 332.000 C SHEAR CALCULATIONS
475 • 333.000 SR1TL=R1
476 • 334.000 SLTR2=R1-BLAWT*NZ*FS
477 • 335.000 C MOMENT CALCULATIONS
478 • 336.000 MR1TL=R1*X
479 • 337.000 MLTR2=R1*(L1-L8)+BLAWT*NX*H8*FS

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480	338.000		$1 + (R1 \cdot BLAWT \cdot N7 \cdot FS) \cdot 1.0$
481	339.000	C	TORQUE CALCULATIONS
482	340.000		$TR2TR1 = PV \cdot (.4 \cdot VR \cdot 12. + HF \cdot (HL \cdot HL / (2 \cdot HL + WBCT \cdot 12.)))$
483	341.000	C	FWD SECTION WEIGHT CALCULATIONS
484	342.000		$G1 = K1 \cdot SFW$
485	343.000		$G2 = 3.08 \cdot VC \cdot .78 \cdot (1. + 2. \cdot PC) \cdot .35$
486	344.000		$WFW = 6800.$
487	345.000		$RHAW = .08$
488	346.000		$GW = 2. \cdot ((.75 \cdot 2. \cdot PC + 144. \cdot SW) / (4. \cdot WFW \cdot 2.61)) \cdot .5 \cdot SW \cdot RHAW \cdot 144.$
489	347.000		$GS = .5 \cdot (GW / A.) \cdot .5 \cdot 288.$
490	348.000		$G3 = GW + GS$
491	349.000		$G4 = .38 \cdot Q \cdot .3 \cdot SNO$
492	349.500		$FNG = BLAWT \cdot 119000. / 215115.$
493	350.000		$G5 = .039 \cdot (FNG \cdot .001 \cdot LNG) \cdot .9$
494	351.000		$G6 = G4 + G5$
495	352.000		$G7 = K7$
496	353.000		$G8 = G1 + G2 + G3 + G4$
497	354.000		$G9 = G8 + G7$
498	355.000	C	CENTER SECTION WEIGHT CALCULATIONS
499	356.000		$PLX = MR1TL / HL$
500	357.000		$PLY = MLTR2 / HL$
501	358.000		$AX = PLX / FAL$
502	359.000		$AY = PLY / FAL$
503	360.000		$G10 = (AX + AY) \cdot 1.28 \cdot RH0L \cdot (L1 \cdot X)$
504	361.000		$TBYT = (TR2TR1 / (WBCT \cdot 12. \cdot HL)) \cdot (1. / TAUS)$
505	362.000		$IF(TBYT \cdot LE \cdot TMIN) TBYT = TMIN$
506	363.000		$TBY = (SLTR2 / HI) \cdot (1. / TAUS)$
507	364.000		$IF(TBY \cdot IF \cdot TBYT) TBY = TBYT$
508	365.000		$TBX = (SRITL / HI) \cdot (1. / TAUS)$
509	366.000		$IF(TBX \cdot IF \cdot TMIN) TBX = TMIN$
510	367.000		$TRAVG = (TRY + TRX) / 2.$
511	368.000		$G11 = TRAVG \cdot (L1 \cdot X) \cdot (2. \cdot HL + WBCT \cdot 12.) \cdot RH0S \cdot 1.28$
512	369.000	C	CENTER SECTION FRAME CALCULATION
513	370.000		$CF = 1. / 14000.$
514	371.000		$DF = 4.0$
515	372.000		$XCSFC = (4.0 \cdot CF \cdot MI \cdot TR2 \cdot (WBCT \cdot 12.) \cdot .2) / (LFS \cdot EF \cdot DF \cdot .2)$
516	373.000		$WBM = XCSFC \cdot (WBCT \cdot 12. + 2. \cdot HF) \cdot RH0F / LFS$
517	374.000		$SXCSEC = (2. \cdot DF \cdot PL \cdot HL \cdot HL \cdot LFS) / (DF \cdot FAF \cdot R.)$
518	375.000		$BXCSEC = (144 \cdot DF \cdot PL \cdot WBCT \cdot WBCT \cdot LFS) / (4. \cdot DF \cdot FAF)$
519	376.000		$WRP = (SXCSEC \cdot 2. \cdot HL + BXCSEC \cdot WBCT \cdot 12.) \cdot RH0F / LFS$
520	377.000		$IF(WBP \cdot IF \cdot WBM) WBP = WBM$
521	378.000		$G12 = WRP \cdot (L1 \cdot X) \cdot 1.28$
522	379.000	C	CENTER SECTION BULKHEAD CALCULATION
523	380.000		$G13 = RH0B \cdot ((R1 / (2. \cdot FAF)) \cdot (4. \cdot HF + 2. \cdot WBCT \cdot 12.))$
524	381.000		$1 + (R1 \cdot WBCT \cdot 12. / (2. \cdot TAUS))) \cdot 1.28$
525	382.000		$G14 = RH0B \cdot ((R2 / (2. \cdot FAF)) \cdot (4. \cdot HF + 2. \cdot WBCT))$
526	383.000		$1 + (R2 \cdot WBCT / (2. \cdot TAUS))) \cdot 1.28$
527	384.000		$G15 = G13 + G14$
528	385.000		$G16 = K2 \cdot 300.$
529	386.000	C	CENTER SECTION WING PROVISION CALCULATION
530	387.000		$G17 = .8 \cdot (BLAWT \cdot .001 \cdot WNZ) \cdot (WB / CBS \cdot (WHTFA / 57.2958)) \cdot .01$
531	388.000		$G18 = G10 + G11 + G12 + G15 + G16 + G17$
532	389.000	C	CENTER SECTION DOOR CALCULATION
533	390.000		$G19 = 1.525 \cdot ACD$
534	391.000		$G20 = 1.02 \cdot (L1 \cdot X) \cdot K3$
535	392.000		$G21 = 660.$
536	393.000		$G22 = G20 + G21$
537	394.000		$G23 = K4$
538	395.000		$G24 = G18 + G19 + G22 + G23$
539	396.000	C	COVER CALCULATIONS
540	397.000	C	COVER SHELL CALCULATION

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DETAIL LISTING (Continued)

541	398.000		G25=SAW*TBV*RWBS*144.*1.28*1.3
542	399.000	C	COVER FRAME CALCULATION
543	400.000		G26=220.*WBP*(2.*HF+2.*WBCT*12.)/(2.*HL+WBCT*12.)*1.28*1.3
544	401.000	C	COVER LONGRAN CALCULATION
545	402.000		G27=110.*AY*RHBL*2.*1.28*1.3
546	403.000		G28=G25+G26+G27
547	404.000	C	THRUST STRUCTURE CALCULATIONS
548	405.000	C	THRUST POST
549	406.000		LF=(LTV**2+HTV**2)**.5
550	407.000		FTP=FT*.00395
551	408.000		G29=((TAV*NBENG8)/FTP)*LF*RWHTP*DFAC*2.
552	409.000	C	THRUST GIMBAL PLANE BULKHEAD
553	410.000		G30=RHBP*((TAV*NBENG8*SIN(A91/57.2958)/(2.*FAPB)
554	411.000		1*DFAC*F81)*(4.*HF+2.*WBCT*12.)+(TAV*NBENG8*SIN(A91/57.2958)
555	412.000		2*WBCT*12.)/(2.*TAUPB1))*2.
556	413.000		G31=NBENG8*200.
557	414.000		G32=G29+G30+G31
558	415.000		G33=K6
559	416.000		G34=A*7*(PV*.001)**.6
560	417.000		G35=G25+G26+G27+G32+G34
561	418.000		G36=G35+G33
562	419.000		G37=G9+G24+G36
563	420.000		RETURN
564	421.000		END
565	422.000		SUBROUTINE THERM(WSG,WESG,TSG,TBTPS,TWGT,WGWT,WGLEWT,TWT,TLEWT
566	422.200		1,RLBTPS,BASEWT,1BTWT,PTPSCN,TTWT,BTPSWT,MCSWT,LDWT
567	422.400		2,PRAWT,PPPC,PHYC,SCWT)
568	423.000		14PI1CIT REAI(A-Z)
569	424.000		COMMON/MAIN/PRAPB,PRAPB,BBT,BCANT,BCANT,BCANTY
570	425.000		1,BCANTP,NBENG8,NBENG8,THBSL,THBSL,THBV,TBV,FLBWR
571	426.000		2,TF,FTW,FXHRD
572	427.000		3,ISPRS,ISPRV,ISPBS,ISPBV,SCD,BTW
573	428.000		4,H,DVCRR,INC,STAGV,DVCN,DVCNST
574	429.000		5,REF,THBTC,THBSL,THBTC,ISPA,ISPR,PRAPOT
575	430.000		6,PRAPB1,PRAPB2,FW(2),DVENC,DVB,DVTOTC,WBSCD,RINWT,BLANWT
576	431.000		7,RINWT,ALWT,BGLW,GLW,TOTAL,S,P,MATCH,TLSSR,FPRP
577	432.000		8,BHBLD,BLLPL,BLWLB,BMSIS,BMSDV,BMSDVP,BMR
578	433.000		9,LBNGP,TAW,TAW,SENS,GRW,MINGLW
579	434.000		COMMON/THERD,NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS
580	435.000		1,CSA,CBTPS,CRA,ATTPS,ATA,ASTPS,ASA,ABTPS,ABA,BASTPS
581	436.000		2,BASA,TPSCN,WBTPS,WGLE,WTTPS,TLTPS,TLPLE
582	437.000		3,TLTPS,MCSPTS,MCSA,WACN,TACN,1BA,1BTPS,IBC,LOA
583	438.000		4,LDTPS,PRRA,PRBTPS,PRBC,PPC,PHYC,SCA,SCTPS,SWI,SWC,WSI
584	439.000		SWC=WSG
585	440.000	C	W/S CORRECTION
586	441.000		WSC=BLANWT/(SWT+SWC)
587	442.000		DUWT=(WSC/WSI)**.125
588	443.000	C	BODY TPS WEIGHT
589	444.000		NCWT=NCTPS*NCA*DUWT
590	445.000		FWDWT=FWDTPS*FWDA*DUWT
591	446.000		CTWT=CTTPS*CTA*DUWT
592	447.000		CSWT=CSTPS*CSA*DUWT
593	448.000		CBWT=CBTPS*CRA*DUWT
594	449.000		CTATA=CTA+CSA+CRA
595	450.000		CTATWT=CTWT+CSWT+CBWT
596	451.000		ATWT=ATTPS*ATA*DUWT
597	452.000		ASWT=ASTPS*ASA*DUWT
598	453.000		ABWT=ABTPS*ABA*DUWT
599	454.000		ATATA=ATA+ASA+ABA
600	455.000		ATATWT=ATWT+ASWT+ABWT
601	455.500		BLBTPS=NCWT+FWDWT+CTATWT+ATATWT



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602	=	456.000	BASFWT=RASTPS*BASA*DUWT
603	=	457.000	IBTWT=IBA*IBTPS+IBC
604	=	458.000	BTPSWT=NCWT+FWOWT+CTATWT+ATATWT+BASFWT+TPSCBN+IBTWT
605	=	459.000	C WING TPS WEIGHT
606	=	460.000	WGW=WESG*WACON
607	=	461.000	WGLFA=WGWA*WGPLE
608	=	462.000	WGTPSA=WGWA*WGLFA
609	=	463.000	WGW=WGTPSA*WGTPS*DUWT
610	=	464.000	WGLEWT=WGLFA*WLETPS*DUWT
611	=	465.000	TWGW=WGW+WGLEWT
612	=	466.000	C TAIL TPS WEIGHT
613	=	467.000	TWA=TS*G*TAACN
614	=	468.000	TLFA=TWA*TLPIF
615	=	469.000	TTPSA=TWA-TLFA
616	=	470.000	TNT=TTPSA*TLTPS*DUWT
617	=	471.000	TLFWT=TLFA*TLTPS*DUWT
618	=	472.000	TTWT=TW+TLFWT
619	=	473.000	MCSWT=MCS*TPS*MCSA*DUWT
620	=	474.000	LDTWT=LCA*LDTPS
621	=	475.000	PRBWT=PRBA*PRBTPS*PRAC
622	=	476.000	SCWT=SCA*SCTPS
623	=	477.000	TATTPS=BTPSWT+TWGW+TTWT+MCSWT
624	=	478.000	1+LDTWT+PRBWT+PPC+HYC+SCWT
625	=	478.200	PTPSCN=TPSCBN
626	=	478.400	PPPC=PPC
627	=	478.600	PHYC=HYC
628	=	479.000	RETURN
629	=	480.000	END
630	=	481.000	SUBROUTINE ASCENT(YAPRBP,FNGPAC,FNG,TVC,CNTR,PRPUTL
631	=	482.000	1,PRRYS,FAD,PRES,CHIL,PREFVAL,FEEDS,DISC,MISC)
632	=	483.000	REAL MISC,MISCF,JAC,NBNGA
633	=	484.000	COMMON/MAIN/ PRBPB,PRBPB,BPT,BCANT,BCANT,BCANTY
634	=	485.000	1,BCANTP,NBNGB,NBNGA,THBSL,THOSL,THAV,TBV,FLWR
635	=	486.000	2,TF,FTW,FXHRD
636	=	487.000	3,ISPRS,ISPBV,ISPBBS,ISPBBSV,SCD,RTW
637	=	488.000	4,H,DVCGR,INC,STAGV,DVCBN,DVCNST
638	=	489.000	5,RFL,THATC,TWBSI,T,THATC,ISPA,ISPB,PRBPB
639	=	490.000	6,PRBPB1,PRBPB2,FX(P),DV8NC,DVB,DVBTC,W8SCD,GINWT,OLANWT
640	=	491.000	7,GINJWT,ALGNT,BGLW,GL9W,TOTAL,S,P,MATCH,TLSSR,FPRP
641	=	492.000	8,BHOLD,BLLPLQ,BLWLB,OMSISP,MSDVT,MSDVP,BMR
642	=	493.000	9,LONGP,TAWB,TBWR,SENS,GRW,MINGLW
643	=	494.000	COMMON/ASPD/POGA,SPI,HHEAD,BHEAD,HULL,BULL,FTU,RHO
644	=	495.000	1,MATL,HLEN,ACLFN,HLEN,BFLFN,CPLGI
645	=	496.000	BENG=3.0
646	=	497.000	BAENG=6326.
647	=	498.000	ESLP=1.225
648	=	499.000	BFTWT=472000.
649	=	500.000	BPUTL=10.
650	=	501.000	BFAO=773.
651	=	502.000	BPRES=1097.
652	=	503.000	BCHT=133.
653	=	504.000	BRECIR=385.
654	=	505.000	BDAIN=12.
655	=	506.000	BPOB=100.
656	=	507.000	BDAID=17.
657	=	508.000	GES=3.
658	=	509.000	SUPTF=24.
659	=	510.000	HDBR=50.
660	=	511.000	BDDBR=50.
661	=	512.000	MISC=10.
662	=	513.000	C CALCULATE MAIN ENGINE WT.

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663	514.000	ECST=BAENG/BETHST**ESLP
664	515.000	ENGU=ECST*TBV**ESLP
665	516.000	ENG=NBENG8*ENGU
666	517.000	C CALCULATE TVC WT.
667	518.000	TVCU=.000422*TBV*208.
668	519.000	TVC=TVCU*NBENG8
669	520.000	C CALCULATE IGNITION AND CONTROL WT.
670	521.000	CONTR=377.+.47.*NBENG8*P8G8*NBENG8*53.34
671	522.000	C CALCULATE PROPELLANT UTILIZATION SYS WT.
672	523.000	PRPUTL=PRPUTL
673	524.000	C CALCULATE FILL AND DRAIN WT.
674	525.000	FAD=FFAD
675	526.000	C CALCULATE PRESSURIZATION SYS WT.
676	527.000	PRFS=HPRFS*((TBV*NBENG8)/(BETHST*BENG8))**.5
677	528.000	C CALCULATE CHILLDOWN DUMP SYS WT.
678	529.000	CHIL=(BCHIL/BENG8)*((TBV/BETHST)**.5*NBENG8)
679	530.000	C CALCULATE RECIRC SYS WT.
680	531.000	RECIR=B*RECIR*((TBV*NBENG8)/(BETHST*BENG8))**.5*SPI
681	532.000	IF(SPI.GT.0.) CHIL=0.
682	533.000	C CALCULATE PRE VALVE WT.
683	534.000	DIATN=BDIATN*(TBV/BETHST)**.5
684	535.000	VALVE=1.582*DIATN**1.78
685	536.000	B2PV=NBENG8*(VALVE*P8G8*B8P8G8)
686	537.000	H2PV=NBENG8*VALVE
687	538.000	C CALCULATE EXT TANK DISCONNECT WT.
688	539.000	DIAD=BDIAD*((TBV*NBENG8)/(BETHST*BENG8))**.5
689	540.000	DIADR*(.125*DIAD**2.)*.5
690	541.000	DIADR*SPI*(.5*DIAD**2.)*.5
691	542.000	IF(SPI.EQ.0.) DIADR=DIAD
692	543.000	H2DV=1.582*DIADR**1.78
693	544.000	B2DV=SPI*2.*1.582*DIADR**1.78
694	545.000	IF(SPI.EQ.0.) B2DV=H2DV
695	546.000	C CALCULATE FEED DUCT WT.
696	547.000	HPRFS=HULL+HWFAD*GES*4.4/1728.
697	548.000	BPRFS=HULL+HWFAD*GES*71.1/1728.
698	549.000	TWD=HPRFS*DIAD/FTU
699	550.000	TWDM=0.
700	551.000	IF(MATL.EQ.1) TWDM=.002*DIAD+.008
701	552.000	IF(MATL.EQ.2) TWDM=.003*DIAD+.010
702	553.000	IF(MATL.EQ.3) TWDM=.003*DIAD+.030
703	554.000	IF(MATL.EQ.4) TWDM=.002*DIAD+.024
704	555.000	IF(TWDM.GT.TWD) TWD=TWDM
705	556.000	TBD=BPRFS*DIAD9/FTU
706	557.000	TBDM=0.
707	558.000	IF(MATL.EQ.1) TBDM=.002*DIADR+.008
708	559.000	IF(MATL.EQ.2) TBDM=.003*DIADR+.010
709	560.000	IF(MATL.EQ.3) TBDM=.003*DIADR+.030
710	561.000	IF(MATL.EQ.4) TBDM=.002*DIADR+.024
711	562.000	IF(TBDM.GT.TBD) TBD=TBDM
712	563.000	THE=HPRFS*DIATN/FTU
713	564.000	TBE=BPRFS*DIATN/FTU
714	565.000	TFM=0.
715	566.000	IF(MATL.EQ.1) TFM=.002*DIATN+.008
716	567.000	IF(MATL.EQ.2) TFM=.003*DIATN+.010
717	568.000	IF(MATL.EQ.3) TFM=.003*DIATN+.030
718	569.000	IF(MATL.EQ.4) TFM=.002*DIATN+.024
719	570.000	IF(TFM.GT.THE) THE=TFM
720	571.000	IF(TBE.GT.TFM) TBE=TFM
721	572.000	HDUCT=HLEN*3.1416*DIAD*TWD*RH8
722	573.000	A*HLEN*NBENG8*3.1416*DIATN*THE*RH8
723	574.000	JAC=HLEN*(3.1416/2.)*(2.*DIAD)*3.1416*.012

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TABLE 3.0-3  
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724 • 575.000      X*.286*HLEN*NBENG8*3.1416/2.*(2.+DIAIN)*3.1416
725 • 576.000      X*.012*.286*(HLEN*(1.+DIAD)*3.1416*1.
726 • 577.000      X+HLEN*NBENG8*(1.+DIAD)*3.1416*1.)*5./1728.
727 • 578.000      HDUCT*HDUCT+JAC
728 • 579.000      BDUCT*BCLEN*3.1416*DIAD8*TR8*RH8*(1.+SPI)
729 • 580.000      X+BFLEN*NBENG8*3.1416*DIAD*TR8*RH8
730 • 581.000      Y=.012
731 • 582.000      Z=R.98
732 • 583.000      IF(CPLG1.EQ.1.) Y=.126
733 • 584.000      IF(CPLG1.EQ.1.) Z=R.24
734 • 585.000      HCBUPL=.2*NBENG8*(Y*DIADIN+Z*.193*DIADIN)
735 • 586.000      X+NBENG8*(Y*DIADIN+Z*(.286+RH8)*DIADIN/2.)
736 • 587.000      X+NBENG8*(Y*DIADIN+Z*RH8*DIADIN)
737 • 588.000      X*(Y*DIAD+Z*(.1+RH8)*DIAD/2.)
738 • 589.000      X=(Y*DIADIN+Z*(.286+RH8)*DIADIN/2.)*NBENG8
739 • 590.000      IF(RH8.GT.2.) HCBUPL=HCBUPL*X
740 • 591.000      BCBUPL=.2*NBENG8*(Y*DIADIN+Z*.193*DIADIN)
741 • 592.000      X+NBENG8*(Y*DIADIN+Z*(.286+RH8)*DIADIN/2.)
742 • 593.000      X+NBENG8*(Y*DIADIN+Z*RH8*DIADIN)
743 • 594.000      X*(1.+SPI)*(Y*DIAD8+Z*(.1+RH8)*DIAD8/2.)
744 • 595.000      X=(Y*DIADIN+Z*(.286+RH8)*DIADIN/2.)*NBENG8
745 • 596.000      IF(RH8.GT.2.) BCBUPL=BCBUPL*X
746 • 597.000      X=INT(HLEN/300.)
747 • 598.000      HBELAS=X*.04178*DIAD**2.1+NBENG8
748 • 599.000      X*(.04178*DIAD**2.1+2.*.01854*DIADIN**2.8)
749 • 600.000      X=INT(BCLEN/300.)
750 • 601.000      BBELAS=X*.1475*DIAD8**2.05+NBENG8
751 • 602.000      X*(.1475*DIADIN**2.05+2.*.03451*DIADIN**2.86)
752 • 603.000      HSUPT=.01*SUPTF*(HCBUPL+H2PV+H2DV+HDUCT+HBELAS)
753 • 604.000      BSUPT=.01*SUPTF*(BCBUPL+B2PV+B2DV+BDUCT+BBELAS)
754 • 605.000      HDR=HDBAR
755 • 606.000      BDR=BDBAR
756 • 607.000      B2FD=BCAUPL+ADUCT+BFELAS+ASUPT+BDR
757 • 608.000      H2FD=HCAUPL+HDUCT+BFELAS+HSUPT+HDR
758 • 609.000 C      CALCULATE MISC WT.
759 • 610.000      MISC=.01*MISC*(TVC+CNTR+PRPUTL+FAD
760 • 611.000      X+PRES+CHIL+RECIR+B2PV+H2PV+H2DV+B2DV
761 • 612.000      X+2FD+H2FD)
762 • 613.000 C      SUM DRY WT.
763 • 614.000      ATOT=MISC/(.01*MISC)+MISC+ENG
764 • 616.000 C      MAIN ASCENT OUTPUT
765 • 617.000      ENGPAC=ENG+TVC+CNTR+PRPUTL
766 • 618.000      PREVAL=B2PV+H2PV
767 • 619.000      FEEDS=B2FD+H2FD
768 • 620.000      DISC=B2DV+H2DV
769 • 621.000      PRBSYS=FAD+PRES+CHIL+PREVAL+FEEDS+DISC+MISC
770 • 622.000      TAPRBP=ENGPAC+PRBSYS
771 • 623.000      RETURN
772 • 624.000      END
773 • 625.000      SUBROUTINE LADSYS(I,NDK,NG1,NG2,NG3,NGEAR,MG1,MG2,MG3
774 • 626.000      1,NGEAR,AX1,AX2,AX3,AXGEAR,LNDDKK)
775 • 627.000      IMPLICIT REAL (A-Z)
776 • 628.000      COMMON/MAIN/ PRAPB,PROPB,BRT,BCANT,BCANT,BCANTY
777 • 629.000      1,BCANTP,NBENG8,NBENG8,THBSL,THBSL,THAV,T8V,FL9WR
778 • 630.000      2,TF,FTW,FIXHRD
779 • 631.000      3,ISPRB,ISPRV,ISPRBS,ISPRBY,ISPRBTW
780 • 632.000      4,REL,THBTC,THBSLT,THBTC,ISPR,ISPB,PRAPBT
781 • 633.000      5,PRAPB1,PRAPB2,FW(2),DV8NC,DVB,DVT8TC,W8SCD,BINWT,BLANWT
782 • 634.000      6,PRAPB1,PRAPB2,FW(2),DV8NC,DVB,DVT8TC,W8SCD,BINWT,BLANWT
783 • 635.000      7,BINJMT,BLOWT,BGLBW,GLBW,TOTAL,S,P,MATCH,TLSSR,FPRP
784 • 636.000      8,BHOLD,ALLPLA,BL8WI,B,MSISP,MSDVT,MSDVP,BMR

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785	637.000	9, LONGP, TAWB, TOWB, SFNS, GRW, MINGLW
786	638.000	COMMON/LDGD/ LGFTU, LGVSL, LGLC, LGLS, LGDIA, BRCF
787	641.000	MGR=PLANWT*235000./215000.
788	642.000	NGR=PLANWT*79000./215000.
789	643.000	PHI=0.
790	644.000	THETA=45.
791	645.000	THETA=THETA*3.14159/180.
792	646.000	PHI=PHI*3.14159/180.
793	647.000	NUMNT=2.
794	648.000	NUMW=4.
795	649.000	L1=LGLC
796	650.000	L2=.2*LGLC
797	651.000	L3=.5*LGLS
798	652.000	L4=.5*LGLC
799	653.000	L5=25.5
800	654.000	L6=9.
801	655.000	LR=L4*TAN(PHI)
802	656.000	L7=L6+L3/TAN(THETA)*L8
803	657.000	D=9.
804	658.000	BRKWT = (PLANWT/12R, R)*((1.6878*LGVSL)**2.)/BRCF
805	659.000	SP=MGR
806	660.000	TWTT = SP*.00687/2.
807	661.000	TWH=SP/(266.666667*2.)
808	662.000	AXLES = TWH*.44226
809	663.000	VR=.5*PLANWT*1.4
810	664.000	DR=.4*PLANWT*1.4
811	665.000	VI = .4*VR
812	666.000	VR = .6 * VR
813	667.000	VC = (1./L7)*(VR*(15+L8)-VI*(L5+L8))
814	668.000	SC = VC/TAN(THETA)
815	669.000	VA = (1./L1)*(LGLS*DR+((VR+VC)*(L1/2.)))
816	670.000	VB = VR+VC+VA
817	671.000	MAA=.5*1.1*(VA+VR)=1.4*DR
818	672.000	AC = 1.26*((MAA/(.85*LGVSL))**.20/3.0))
819	673.000	RC = SQRT(AC/.596902604165)
820	674.000	WC = AC*(LGLC-L2)*.283
821	675.000	BRACE = .1*WC
822	676.000	B = 2.*RC*9.*SIN(PHI)
823	677.000	BETA = ATAN((L2+L4)/L1)
824	678.000	LA = (.8*L1-RC)/(COS(BETA)*COS(PHI))
825	679.000	MSIDEF = (VB*COS(PHI)+SC*SIN(PHI))*COS(BETA)*LA
826	680.000	MFRANT = (VR*SIN(PHI)-SC*COS(PHI))*LA
827	681.000	D1 = (729.-(54.*MSIDEF)/(LGFTU*(2.*RC-9.*SIN(PHI))))**.1/3.)
828	682.000	D4 = 6.*MFRANT/(4.*LGFTU*RC*RC)
829	683.000	AF = (D-(D1+D4))*8*(D1-D4)
830	684.000	WFA = 1.05*AF*LA*.283*.5
831	685.000	MSIDEP = ((VR*COS(PHI)+SC*SIN(PHI))*COS(BETA)-DR*SIN(BETA))*LA
832	686.000	D1P = (729.-(54.*MSIDEP)/(LGFTU*(2.*RC-9.*SIN(PHI))))**.1/3.)
833	687.000	AA = (D-(D1P+D4))*8*(D1P+D4)
834	688.000	WAA = 1.05*AA*LA*.283*.5
835	689.000	MP = DR*(LGLS-LGLC)
836	690.000	AP = 1.26*(MP/LGVSL)**(2./3.)
837	691.000	WP = 1.5*AP*LGLC*.283
838	692.000	TWSSC = WAA+WFA+WC+BRACE
839	693.000	ATF = .04*TWSSC*.1
840	694.000	WT = TWSSC + WP+BRKWT+TWTT+AXLES+ATF+TWH
841	695.000	MCANTM = .225*(WT*.95)
842	696.000	WT = WT + MCANTM
843	697.000	THETA2 = THETA*180./3.14159
844	698.000	PHI2 = PHI*180./3.14159
845	699.000	SPN = NGR/NUMNT

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DETAIL LISTING (Continued)

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R46 = 700.000 WNT = SPN*.006675
R47 = 701.000 TWNT = WNT*NUMNT
R48 = 702.000 WHN = SPN/266.66667
R49 = 703.000 AXLN = WHN*.44226
R50 = 704.000 STN = TWSSC*.40
R51 = 705.000 ATFN = .06*TWSSC**1.1
R52 = 706.000 WTNG = TWNT+WHN+AXLN+STN+ATFN
R53 = 707.000 NCNTN = (WTNG**0.95)**.850
R54 = 708.000 WTNG = WTNG+NCNTN
R55 = 709.000 WC = WC*1.25
R56 = 710.000 WFA = WFA*1.25
R57 = 711.000 WAA = WAA * 1.25
R58 = 712.000 BRACE = BRACE * 1.25
R59 = 713.000 TWSSC = TWSSC * 1.25
R60 = 714.000 AXLES = AXLES*1.25
R61 = 715.000 WP = WP * 1.25
R62 = 716.000 MCNTM = MCNTM*1.25
R63 = 717.000 ATF = ATF*1.25
R64 = 718.000 BRKWT = BRKWT * 1.25
R65 = 719.000 TWTT = TWTT*1.25
R66 = 720.000 TWH = TWH*1.25
R67 = 721.000 WT = TWSSC+WP+BRKWT + TWTT+AXLES+ATF+TWH+MCNTM
R68 = 722.000 TWNT = TWNT*.80
R69 = 723.000 WHN = WHN*.80
R70 = 724.000 AXLN = AXLN*.80
R71 = 725.000 STN = STN*.80
R72 = 726.000 ATFN = ATFN*.80
R73 = 727.000 NCNTN = NCNTN*.80
R74 = 728.000 WTNG = TWNT+WHN+AXLN+STN+ATFN+NCNTN
R75 = 729.000 NG1 = TWNT+WHN
R76 = 730.000 NG2 = STN+AXLN+ATFN
R77 = 731.000 NG3 = NCNTN
R78 = 732.000 NGFAR = NG1+NG2+NG3
R79 = 733.000 MG1 = (TWH+TWTT+BRKWT)*2.
R80 = 734.000 MG2 = (TWSSC+AXLES+ATF+WP)*2.
R81 = 735.000 MG3 = (MCNTM)*2.
R82 = 736.000 MG4 = MG1+MG2+MG3
R83 = 737.000 AX1 = 1.5*(1.82*(1.0074*(.07528/(2.*32.2)*(1.6878*LGVSU)**2)**0.57
R84 = 738.000 X*(LGDI1+LGDI1+3.*LGDI1)+10.))
R85 = 739.000 AX2 = AX2
R86 = 740.000 AX3 = AX3
R87 = 741.000 AXGFAR = AX1+AX2+AX3
R88 = 742.000 LNDDK = NGFAR+MG4+AXGFAR+LNDDKK
R89 = 743.000 RETURN
R90 = 744.000 END
R91 = 745.000 SUBROUTINE OUTPUT
R92 = 746.000 IMPLICIT REAL (A-Z)
R93 = 747.000 COMMON/MAIN/ PRP8,PRP8,BBT,BCANT,BCANT,BCANTY
R94 = 748.000 1,BCANTP,NBENG8,THBSL,THBSL,THBV,TBV,FLWR
R95 = 749.000 2,TF,FTW,FXHRD
R96 = 750.000 3,ISPRS,ISPRV,ISPB8S,ISPB8V,SCD,BTW
R97 = 751.000 4,H,DVCBR,INC,STAGV,DVCBN,DVCNST
R98 = 752.000 5,REL,THBTC,THSLT,THATC,ISPA,ISPB,PRPBT
R99 = 753.000 6,PRPBT1,PRPBT2,FW(2),DV8NC,DVB,DVTBTC,WBSCD,BINWT,BLANWT
R99 = 753.000 7,BINWT,BLAWT,BGLBW,GLOW,TOTAL,S,P,MATCH,TLSSR,FPRP
R99 = 753.000 8,BHOLD,BLLPLQ,BLBW,BMSISP,BMSDVT,BMSDVP,BMR
R99 = 753.000 9,LONGP,TWR,TWR,SENS,GRW
R99 = 753.000 10,CMYBN/SRM8/BBWT,3DRYWT,BGLAW,LAMB,PWBI
R99 = 753.000 11,BASSRM,WCASE,WJ8INT,WB8ZZ,WTTER,WINST,WIGN,BSRMC
R99 = 753.000 12,SRMISS,PWFS,PWASLS,PWAS,PWVF,PWTK,PWAV,WNCTPS,SRMIC
R99 = 753.000 13,WRECOV,PWPAR,PWFI,PWRR,PWRP,PWRR,SRMRC
R99 = 753.000

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907	761.000	4, UNCFRT, EXPINS, PB8SLU, SRML, SRMD
908	762.000	5, PGR8SS, PB88WT, PPR8PB, PDRYWT, PB8SLU
909	763.000	4, FIX888, SIMPR8
910	764.000	COMMON/GR88/R1, R2, RL, WTAUX, WTACS, ACSFNG, ACSSYS, WTACTK
911	764.040	1, ACSMBD, WT8MS, 8MSENG, PR8PSY, WT8MTK, MD8ULE
912	764.080	1, SURFC, PPWR, ELFC, HYDR, AVI8N8, ECL88, PPR8V, 8UNCWT
913	764.120	2, 8RRMIS, TABPR8, SURFK
914	764.160	1, PPR88N, 8RES8, 8RESV, PL8ADD, PL8ADD, ACSPR8, W8PR8P, SUDLE
915	764.200	2, FIX88B, FIX88P, 8DRYWT, 8RIFL
916	764.240	1, WWT, WSG, W8STR, W8888, W8888, LEW, WTE, WAIL, WAS, WADR, WAH
917	764.280	2, WAP, GPR8V, PWINGK, TAIL, TSG, TBSTR, TT888, TLE, WRUD, WRS
918	764.320	3, WRDR, W8H, WRP, PTAILK
919	764.360	1, G37, G1, G2, G3, G4, G7, G8, G9, G10, G11, G12, G15, G16
920	764.400	2, G17, G18, G19, G22, G23, G24, G25, G26, G27, G32, G33, G34
921	764.440	3, G35, G36
922	764.480	1, TBTPS, TWGWT, WGWT, WGLEWT, TWT, TLEWT, BLBTPS
923	764.520	2, BASEWT, 1BTWT, PTPSCN, TTWT, BTPSWT, MCSWT, LDTWT
924	764.560	3, PR8WT, PP8C, PHYC, SCWT
925	764.600	1, TAP88P, ENG8AC, ENG, TVC, CNTR, PRPUTL, PR8SYS
926	764.640	2, FAD, PR8C, CHIL, PREVAL, FEEDS, DISC, MISC
927	764.680	1, LND8K, NG1, NG2, NG3, NG8AR, MG1, MG2, MG3, MG8AR, AX1, AX2
928	764.720	2, AX3, AX88AR, LND8K
929	780.000	COMMON/EXT8/8888P, TBTPS, FWT8K, FAIRT, FWOBLF, FCCTPS
930	781.000	1, CN8CT, TPSIN, CYL8CT, ACYDM, AFT8LF, WINT, PR8SY, AFT8K
931	782.000	2, FE8SYS, FWD8A, PR8VNT, AFT8YL, SUMP, AFT8LA, P8PU, TWINT
932	783.000	3, NG88AR, AVI8NT, 8888P, W888P, TUNNEL, MISC8, BAFF, SUBDRY
933	784.000	4, GU, DRY8T, RESIDT, UNDR8N, FEED8R, PR8URT, FBIAS, INERT
934	785.000	5, 8888W, TL88P, 8888P, EXT8L, EXT8D, BLK8D, EXT88, EXT8H, SIMPTK
935	786.000	COMMON/DV8/DVT, DV8A, DV8, DV8R, DV88P, X2, X3
936	787.000	1, DV88P, TBTL88, DV88R, DVALT
937	788.000	WRITE(108, 2000)
938	789.000	WRITE(108, 2010) WSG, WWT
939	790.000	WRITE(108, 2020) W8STR, W8888, W8888, LEW, WTE, GPR8V, GPR8V
940	791.000	1, WAIL, WAS, WADR, WAH, WAP, PWINGK
941	792.000	WRITE(108, 2030) TSG, TAIL
942	793.000	WRITE(108, 2040) TBSTR, TT888, TLE, WRUD, WRS, WRDR, WRH
943	794.000	1, WRP, PTAILK
944	795.000	WRITE(108, 2050) G37
945	796.000	WRITE(108, 2060)
946	797.000	WRITE(108, 2070) G1, G11, G25, G10, G27, G12, G26, G15, G2, G3
947	798.000	1, G6, G16, G17, G32, G33, G8, G18, G35, G19, G22, G7, G23, G33, G9
948	799.000	2, G24, G34
949	800.000	WRITE(108, 2080) TBTPS
950	801.000	WRITE(108, 2090) TWGWT, WGWT, WGLEWT, TTWT, TWT, TLEWT, BTPSWT
951	802.000	1, BLBTPS, BASEWT, 1BTWT, PTPSCN, MCSWT, LDTWT, PR8WT, PP8C, PHYC
952	803.000	2, SCWT
953	804.000	WRITE(108, 2100) LND8K
954	805.000	WRITE(108, 2110) NG8AR, NG1, NG2, NG3, MG8AR, MG1, MG2, MG3
955	806.000	1, AX88AR, AX1, AX2, AX3, LND8K
956	807.000	WRITE(108, 2120) TAP88P
957	808.000	WRITE(108, 2130) ENG8AC, ENG, TVC, CNTR, PRPUTL, PR8SYS, FAD
958	809.000	1, PR8C, CHIL, PREVAL, FEEDS, DISC, MISC
959	810.000	WRITE(108, 2140) TABPR8
960	811.000	WRITE(108, 2150) WTAUX
961	812.000	WRITE(108, 2160) WTACS, ACSFNG, ACSSYS, WTACTK, ACSMBD, WT8MS
962	813.000	1, 8MSENG, PR8PSY, WT8MTK, MD8ULE
963	814.000	WRITE(108, 2170) PPWR
964	815.000	WRITE(108, 2180) ELFC
965	816.000	WRITE(108, 2190) HYDR
966	817.000	WRITE(108, 2200) SURFC
967	818.000	WRITE(108, 2210) AVI8N8

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968 - 819.000 WRITE(108,2220) EC LSH
969 - 820.000 WRITE(108,2220) PPRSV
970 - 821.000 WRITE(108,2225) BRMYTS
971 - 822.000 WRITE(108,2240) BUNCWT,8DRYWT
972 - 823.000 WRITE(108,2245)
973 - 824.000 WRITE(108,2250) 8DRYWT,PFPSAN,8RESO,PL8ADU,8INWT,8RESV
974 - 825.000 1,8RIEL,ACSPRA,W8PRAP,8TRAP,9L8WT,PL8ADD,8LANWT,PL8ADU,8INJW
975 - 826.000 2000 FORMAT(11,24X,18BITER WEIGHT SUMMARY!)
976 - 827.000 2010 FORMAT(///,4X,1WING GROUP(ARFA=1,F5.0,1),23X,
977 - 828.000 1(1,F9.0,1)!)
978 - 829.000 2020 FORMAT(4X,1BASIC STRUCTURE!,18X,F9.0,
979 - 830.000 1/,9X,1TORQUE BOX EXPOSE!,2X,F9.0,
980 - 831.000 2/,9X,1TORQUE BOX CARRY!,3X,F9.0,
981 - 832.000 3/,9X,1LEADING EDGE!,7X,F9.0,
982 - 833.000 4/,9X,1TRAILING EDGE!,6X,F9.0,
983 - 834.000 5/,6X,1SECONDARY STRUCTURE!,14X,F9.0,
984 - 835.000 6/,9X,1M.L.G. PROVISIONS!,2X,F9.0,
985 - 836.000 7/,6X,1CENTRE SURFACE!,18X,F9.0,
986 - 837.000 8/,9X,1SHELL!,14X,F9.0,
987 - 838.000 9/,9X,1DRIVE RIB!,10X,F9.0,
988 - 839.000 8/,9X,1HINGE!,14X,F9.0,
989 - 840.000 8/,9X,1ATTACH!,12X,F9.0,
990 - 841.000 8/,4X,1WING WEIGHT CONSTANT!,13X,F9.0)
991 - 842.000 2030 FORMAT(4X,1TAIL GROUP(ARFA=1,F5.0,1),23X,
992 - 843.000 1(1,F9.0,1)!)
993 - 844.000 2040 FORMAT(4X,1BASIC STRUCTURE!,18X,F9.0,
994 - 845.000 1/,9X,1TORQUE BOX!,9X,F9.0,
995 - 846.000 2/,9X,1LEADING EDGE!,7X,F9.0,
996 - 847.000 3/,6X,1CENTRE SURFACE!,18X,F9.0,
997 - 848.000 4/,9X,1SHELL!,14X,F9.0,
998 - 849.000 5/,9X,1DRIVE RIB!,10X,F9.0,
999 - 850.000 6/,9X,1HINGE!,14X,F9.0,
1000 - 851.000 7/,9X,1ATTACH!,12X,F9.0,
1001 - 852.000 8/,6X,1TAIL WEIGHT CONSTANT!,13X,F9.0)
1002 - 853.000 2050 FORMAT(4X,1BODY GROUP!,35X,1(1,F9.0,1)!)
1003 - 854.000 2060 FORMAT(11X,1FWD!,8X,1CTR!,8X,1AFT!)
1004 - 855.000 2070 FORMAT(4X,1BASIC STRUCTURE!,
1005 - 856.000 1/,9X,1SIDEWALLS!,10X,F9.0,2X,F9.0,1X,F9.0,
1006 - 857.000 2/,9X,1LANGERANS!,21X,F9.0,1X,F9.0,
1007 - 858.000 3/,9X,1FRAMES!,24X,F9.0,1X,F9.0,
1008 - 859.000 4/,9X,1BULKHEADS!,21X,F9.0,
1009 - 860.000 5/,9X,1CREW CPT. PRV.,1,4X,F9.0,
1010 - 861.000 6/,9X,1WINDSHIELD PRV.,1,3X,F9.0,
1011 - 862.000 7/,9X,1NOSE WHL.WEL PRV.,2X,F9.0,
1012 - 863.000 8/,9X,1PAYLOAD REACTION!,14X,F9.0,
1013 - 864.000 5/,9X,1WING SHEAR PRV.,1,14X,F9.0,
1014 - 865.000 1/,9X,1TRUST STRUCTURE!,25X,F9.0,
1015 - 866.000 2/,9X,1TAIL PRV.,1,31X,F9.0,
1016 - 867.000 3/,6X,1SUB TOTAL!,13X,F9.0,2X,F9.0,2X,F9.0,
1017 - 868.000 4/,6X,1SECONDARY STRUCTURE!,
1018 - 869.000 5/,9X,1CARGO DECK SHELL!,14X,F9.0,
1019 - 870.000 6/,9X,1CARGO DECK MECH.,1,14X,F9.0,
1020 - 871.000 7/,6X,1MISCELLANEOUS WTS.,1,4X,F9.0,2X,F9.0,2X,F9.0,
1021 - 872.000 8/,6X,1TOTAL!,17X,F9.0,2X,F9.0,2X,F9.0)
1022 - 873.000 2080 FORMAT(11,3X,1INDUCED ENVIRON. PRST.,1,23X,
1023 - 874.000 1(1,F9.0,1)!)
1024 - 875.000 2090 FORMAT(4X,1WING!,24X,F9.0,
1025 - 876.000 1/,9X,1SURFACE PANELS!,5X,F9.0,
1026 - 877.000 2/,9X,1LEADING EDGE!,7X,F9.0,
1027 - 878.000 3/,6X,1TAIL!,29X,F9.0,
1028 - 879.000 4/,9X,1SURFACE PANELS!,5X,F9.0,

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1029	880.000	57.9X, 'LEADING EDGE', 7X, F9.0,
1030	881.000	67.6X, 'BODY', 22X, F9.0,
1031	882.000	77.9X, 'BODY PANELS', 8X, F9.0,
1032	883.000	87.9X, 'BASE', 15X, F9.0,
1033	884.000	97.9X, 'INTERNAL TPS', 7X, F9.0,
1034	885.000	107.9X, 'BODY CNST TPS WT.', 2X, F9.0,
1035	886.000	117.6X, 'MIS CNST. SURFACE', 16X, F9.0,
1036	887.000	127.6X, 'LAND + DOCKING', 19X, F9.0,
1037	888.000	137.6X, 'PROPULSION', 23X, F9.0,
1038	889.000	147.6X, 'PRIME POWER', 22X, F9.0,
1039	890.000	157.6X, 'HYDRAULICS', 23X, F9.0,
1040	891.000	167.6X, 'SURFACE CONTRLS', 17X, F9.0,
1041	892.000	2100 FORMAT(4X, 'LANDING & DOCKING', 28X, '(1, F9.0, 1)')
1042	893.000	2110 FORMAT(4X, 'BASE GEAR', 24X, F9.0,
1043	894.000	177.9X, 'ROLL GEAR', 10X, F9.0,
1044	895.000	187.9X, 'STRUCTURE', 10X, F9.0,
1045	896.000	197.9X, 'CENTRIS', 11X, F9.0,
1046	897.000	207.6X, 'MAIN GEAR', 24X, F9.0,
1047	898.000	217.9X, 'ROLL GEAR', 10X, F9.0,
1048	899.000	227.9X, 'STRUCTURE', 10X, F9.0,
1049	900.000	237.9X, 'CENTRIS', 11X, F9.0,
1050	901.000	247.6X, 'AUXILIARY SYSTEMS', 16X, F9.0,
1051	902.000	257.9X, 'DECELERATION SYS', 3X, F9.0,
1052	903.000	267.9X, 'SEPARATION SYS', 5X, F9.0,
1053	904.000	277.9X, 'HANDLING & MANIP', 3X, F9.0,
1054	905.000	287.6X, 'MISCELLANEOUS', 20X, F9.0,
1055	906.000	2120 FORMAT(4X, 'PROPULSION MAIN ASCENT', 23X, '(1, F9.0, 1)')
1056	907.000	2130 FORMAT(4X, 'ENGINES+ACCESSORIES', 15X, F9.0,
1057	908.000	297.9X, 'ENGINES', 12X, F9.0,
1058	909.000	307.9X, 'GIMBAL SYSTEM', 6X, F9.0,
1059	910.000	317.9X, 'CENTRIS', 11X, F9.0,
1060	911.000	327.9X, 'PROPELLANT UTILIZ', 2X, F9.0,
1061	912.000	337.6X, 'PROPELLANT SYSTEM', 16X, F9.0,
1062	913.000	347.9X, 'FILL & DRAIN', 7X, F9.0,
1063	914.000	357.9X, 'PRESSURIZATION', 5X, F9.0,
1064	915.000	367.9X, 'WILL DUMP LINES', 3X, F9.0,
1065	916.000	377.9X, 'REF VALVES', 9X, F9.0,
1066	917.000	387.9X, 'FEED SYSTEM', 8X, F9.0,
1067	918.000	397.9X, 'DISCONNECTS', 8X, F9.0,
1068	919.000	407.9X, 'MISCELLANEOUS', 6X, F9.0,
1069	920.000	2140 FORMAT(4X, 'PROPULSION AIR BRATH', 24X, '(1, F9.0, 1)')
1070	921.000	2150 FORMAT(4X, 'PROPULSION AUXILIARY', 25X,
1071	922.000	1'(1, F9.0, 1)')
1072	923.000	2160 FORMAT(4X, 'ACS SYSTEM', 23X, F9.0,
1073	924.000	417.9X, 'THRUSTERS', 10X, F9.0,
1074	925.000	427.9X, 'PROP. SYSTEM', 7X, F9.0,
1075	926.000	437.9X, 'TANK', 15X, F9.0,
1076	927.000	447.9X, 'MODULE', 13X, F9.0,
1077	928.000	457.6X, 'BMS SYSTEM', 22X, F9.0,
1078	929.000	467.9X, 'THRUSTERS', 10X, F9.0,
1079	930.000	477.9X, 'PROP. SYSTEM', 7X, F9.0,
1080	931.000	487.9X, 'TANK', 15X, F9.0,
1081	932.000	497.9X, 'MODULE', 13X, F9.0,
1082	933.000	2170 FORMAT(4X, 'PRIME POWER', 34X, '(1, F9.0, 1)')
1083	934.000	2180 FORMAT(4X, 'ELECTRICAL', 35X, '(1, F9.0, 1)')
1084	935.000	2190 FORMAT(4X, 'HYDRAULIC', 36X, '(1, F9.0, 1)')
1085	936.000	2200 FORMAT(4X, 'SURFACE CONTRLS', 29X, '(1, F9.0, 1)')
1086	937.000	2210 FORMAT(4X, 'AVIONICS', 37X, '(1, F9.0, 1)')
1087	938.000	2220 FORMAT(4X, 'ENVIRONMENTAL CONTRLS', 24X, '(1, F9.0, 1)')
1088	939.000	2230 FORMAT(4X, 'PERSONNEL PROVISIONS', 25X, '(1, F9.0, 1)')
1089	940.000	2235 FORMAT(4X, 'MISCELLANEOUS', 32X, '(1, F9.0, 1)')



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1090 - 941.000 2240 FORMAT(4X,'GROWTH/UNCERTAINTY',27X,'(1,F9.0,1)')
1091 - 942.000 1//,49X,' - - - - - ',1//,4X,
1092 - 943.000 2'DRY WEIGHT',34X,'(1,F9.0,1)')
1093 - 944.000 2245 FORMAT(///,11,24X,'ORBITER MISSION HISTORY')
1094 - 945.000 2250 FORMAT(//,4X,'DRY WEIGHT',13X,'(1,F9.0,1)')
1095 - 946.000 1//,6X,'PERSONNEL',13X,F9.0,
1096 - 947.000 2//,6X,'ORB REQD PRBP WT',15X,F9.0,
1097 - 948.000 3//,6X,'PAYLOAD UP',12X,F9.0,
1098 - 949.000 4//,4X,'INFRT WEIGHT',11X,'(1,F9.0,1)')
1099 - 950.000 5//,6X,'ORB REQV PRBP WT',15X,F9.0,
1100 - 951.000 6//,6X,'ORB INFLIGHT LASSES',13X,F9.0,
1101 - 952.000 7//,6X,'ACS PRBP WT',11X,F9.0,
1102 - 953.000 8//,6X,'SAMS PRBP WT',10X,F9.0,
1103 - 954.000 9//,6X,'ORB TRAPED PRBP WT',4X,F9.0,
1104 - 955.000 10//,4X,'GROSS WT (ORB ONLY)',5X,'(1,F9.0,1)')
1105 - 956.000 1//,6X,'(LAND WT PAY',1,F6.0,1)')
1106 - 957.000 2//,4X,'LANDING WEIGHT',9X,'(1,F9.0,1)')
1107 - 958.000 3//,6X,'(INJE WT PAY',1,F6.0,1)')
1108 - 959.000 4//,4X,'INJECTED WEIGHT',8X,'(1,F9.0,1)')
1109 - 960.000 RETURN
1110 - 961.000 END

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COMPUTER PROGRAM - FINAL REPORT

REPORT MDC E0746  
VOLUME I  
28 FEBRUARY 1973

3.1 Wing and Tail Torque Box Model - The wing of any aircraft consists of a torque box which carries the primary bending, shear, and torsion loads, and leading and trailing edges to form the proper airfoil contour. Each individual aircraft has a variety of control-surface types and sizes, provisions for engines, fuel systems, and landing gear, dependent on overall configuration, as well as special features, such as wing folds, fairings, stores provisions, etc. Of the total weight of the wing, between 45 and 75 percent consists of the torque box.

An aerodynamic surface weight (AEROSURF) prediction method, based on the concept of a basic wing plus increments for special design features, has been developed and shows good correlation with existing wing and tail surfaces. The major element is the torque box model which consists of:

(a) an airload model for load on exposed surfaces, and root bending moment, based on the method outlined in RAE transonic data Memorandum 6403 (Reference E).

(b) the structural arrangement is a closed, two-spar multirib box subjected to vertical shear and bending moments. A straight, constant-section, body carry through is also computed.

(c) cover skins are analyzed for bending load, spar webs for vertical shear load, and ribs for flexure-induced crushing load or cover skin stiffness.

(d) the unit weight-to-load relationship for the cover skins and ribs is developed from a beam column analysis of a single-face corrugated panel. A straight line approximation of the calculated curves is used as suggested by Shanley, Reference (D).

(e) the loading and section areas along the span are integrated into total wing weight by analytical expressions. If significant geometry breaks exist, a tabulated multistation analysis is employed.

(f) allowances are included for specific factors that are known but not easily quantified. An overall torque box contingency factor of 25 percent is developed from correlations to some 19 existing aircraft. These aircraft include a variety of fighters, transports, and bombers assuring the model is valid for a wide range of loading, geometry, and structural arrangements.

AEROSURF is a significant first generation effort at prediction of a wing (or tail) weight with minimum turn around time and effort. It contains a realistic representation for the significant elements of a traditional design cycle, and with the correlation factors, gives accurate quantitative answers as well as correct trends. It is recognized that the model is not truly representative of structural

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arrangements of typical low aspect ratio delta wings. Yet the correlation with existing deltas and apparent agreement with preliminary analysis of Shuttle wings suggests the overall weight is valid.

The following work develops the analytical relationships used in the derivation of the model with a summary of the equations listed in Table 3-1.

**TABLE 3-1  
SUMMARY EQUATIONS**

Exposed Surface	Carrythrough
<u>Bending</u>	
Shell $\gamma_1 = C_B k_{tb} S_{ex}$	$\gamma_2 = 2 C_B k_{tb} C_f b_f$
Bending $\gamma_3 = \frac{\rho L_{ex} k_{\lambda m} k_{\ell cp}}{3 F_A 0.8 h_f} \left( \frac{b_{ex}}{2 \cos \theta} \right)^2$	$\gamma_4 = \frac{\rho k_{\ell cp} L_{ex} b_{ex} (2\lambda' + 1) b_f}{6 F_A 0.8 h_f (\lambda' + 1)}$
<u>Shear</u>	
Intercept/ Min gage $\gamma_5 = \frac{\rho b_{ex}}{\cos \theta} \frac{C_5 (.8 h_f (HM')^2 + t_{min} .8 h_f (1tm'))}{2}$	$\gamma_6 = 2 C_B 0.8 h_f b_f$
Shear $\gamma_7 = \frac{\rho k_{\ell cp} L_{ex} b_{ex} (2\lambda' + 1)}{6 \tan \tau_A \cos \theta (\lambda' + 1)}$	
<u>Ribs</u>	
Strength $\gamma_8 = 2 \rho \int_0^{b/2} \bar{t}_{rx} h_x C_x \frac{1}{a_i} dx$	$\gamma_9 = \frac{2 \rho}{a_i} \bar{t}_{rx} h_f C_f$

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TABLE 3-1  
SUMMARY EQUATIONS (Continued)

where  $\bar{t}_{rx}$  = larger of

$$\frac{C_B h_x}{(.10)(144)} + \frac{N_{mx}}{F_a} \quad \text{or} \quad \frac{67.5 M_x}{\pi^2 E C_x a i}$$

where  $N_{mx}$  is the flexure induced crushing load on the rib.

## JOINTS

$$\gamma_{10} = (\gamma_1 + \gamma_3 + \gamma_5 + \gamma_7 + \gamma_8) .10$$

$$\gamma_{11} = (\gamma_2 + \gamma_4 + \gamma_6 + \gamma_9) .10$$

## STANDARD GAGE

$$\gamma_{12} = .14 S_{exp} k_{tb}$$

$$\gamma_{13} = .14 S_{ct} k_{tb}$$

## MODEL

$$\gamma_{14} = .10 \gamma_3 + .20 \gamma_7 + \gamma_8$$

$$\gamma_{15} = .10 \gamma_4 + .20 \gamma_9$$

## RELIEF

$$W_{REL} = \rho \frac{W_c NZ L_1^2 k''}{FA .8 h_f} + \frac{\rho W_c NZ L_1 BCT . \cos \theta}{FA .8 h_f} + \frac{\rho W_c NZ L_1}{\tau}$$

## KICK RIB

$$W = .058 \left( \frac{SL \sin \theta b_{ex}}{h_f \cos \theta} \right) .92$$

$$\text{Subtotal } \gamma_{16} =$$

$$\text{Non Optimum } \gamma_{18} = .25 \gamma_{16}$$

$$\text{Subtotal } \gamma_{20} =$$

$$\text{Total Torque Box}$$

$$\gamma_{22} =$$

$$\gamma_{17} =$$

$$\gamma_{19} = .25 \gamma_{17}$$

$$\gamma_{21} =$$

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## Symbols used in the equations

$a_i$	- rib spacing	$\bar{\eta}$	- c.p. location as fraction of length
AR	- aspect ratio	JSF	- joints, splices, fasteners
b	- span	$\lambda$	- planform taper ratio
C	- chord length	$\Lambda$	- sweep angle
$C_B$	- intercept of bending shell	$\theta$	- sweep angle of structural axis (normally 0.50 c)
$C_S$	- intercept of shear allowable curve	$\tau$	- allowable shear stress
E	- modulus		
f	- stress		
F	- allowable stress		
$F_A$	- artificial allowable stress		
h	- depth		
$k_{tb}$	- % of chord torque box		
$k_{lcp}$	- correction factor to airload distribution		
$k_{\lambda m}$	- integration factor for planform and thickness taper		
L	- surface load		
$\ell$	- length		
M	- moment		
m	- thickness ratio		
$N_Z$	- normal load factor times factor of safety		
P	- load (lb)		
$N_x$	- unit axial loading (lb/in)		
$N_n$	- unit normal loading		
$\bar{t}$	- equivalent or "smeared" skin thickness		
t	- skin thickness		
$\bar{w}$	- unit weight		
W	- weight		
$\rho$	- density		
$\eta$	- fraction of span, exposed semispan		
S	- Area		

## Superscripts

' - reference to exposed surface

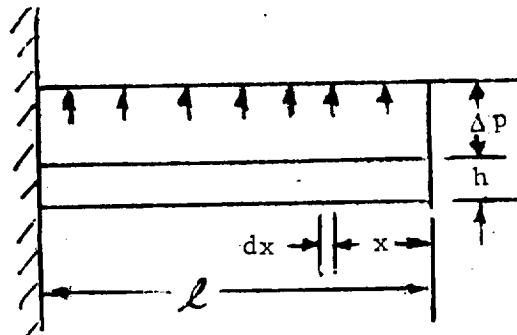
## Subscripts

te - trailing edge  
le - leading edge  
f - fuselage intersection  
t - tip  
o - centerline  
ex - exposed surface  
x - arbitrary station  
r - rib  
c - over

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3.1.1 Basic Analysis Model - The basic analysis model for the torque box is a simple bending beam.



The weight of the beam is the sum of the section weight ( $\rho A_x dx$ )

$$W = \sum_{0}^l \rho A_x dx$$

Assuming both caps are equal, and applied stress is equal to allowable stress, the cross sectional area of the beam at  $x$  is:

$$A_x = \frac{2 P_x}{f} = \frac{2 M_x}{f h} = \frac{\Delta p x^2}{f h}$$

The total beam weight can then be obtained by tabular setup and summation, the multistation analysis method proposed by Kirkpatrick of Boeing in 1952 (Reference F). For surfaces with no discontinuities, the summations are performed analytically since they are quickly solved and lend themselves to use in parametric studies. The beam weight equation is:

$$\begin{aligned} W &= \frac{\rho}{f} \int_0^l \frac{\Delta p x^2}{h} dx \\ &= \frac{1}{3} \frac{\rho \Delta p l^3}{f h} \end{aligned}$$

letting  $\Delta p l$  equal the total load ( $L$ ),

$$W = \frac{\rho L l^2}{3 f h}$$

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The development of the weight equation for a wing follows the same steps as that of the simple beam.

- o from the load model, calculate the shear and bending material at a section
- o determine the unit cap or web loading
- o from the structural model determine the allowable and calculate the section area

- o integrate the section areas over the span to obtain total weight
- o add factors for unanalyzed material and correlate to existing vehicles
- o develop expressions for a geometric break at the wing-fuselage attachment.

## 3.1.2 Airload Distribution -

Spanwise c.p. - The variation in spanwise location of the center of pressure with planform taper ratio ( $\lambda$ ), sweepback angle ( $\Lambda$ ), and aspect ratio (AR), is derived from the method of RAE Transonic Data Memorandum 6403, Reference (E), which is based on Multhopp's subsonic lifting surface theory. Planforms with curved leading edges and arbitrary trailing edges can be estimated by data presented in Reference (E). Figure 3.1-1 presents the spanwise c.p. ( $\bar{\eta}$ ) of surfaces with straight leading and trailing edges as a function of  $\lambda$ ,  $\Lambda$ , and AR.

A single equation can be written for  $\bar{\eta}$  in terms of  $\Lambda_{te}$ ,  $\lambda$ , and AR. The equation is generally accurate to within one percent. This empirical equation was derived knowing the partial derivatives of the variables with-respect to  $\bar{\eta}$ .

$$\bar{\eta} = \left[ 0.04 + AR (0.0049 + 0.000045 (\Lambda_{le})) \right] \lambda - 0.05 (\lambda - 0.4)^2 + 0.41 (1. + .000333 \Lambda_{le}) - \left( \frac{60 - \lambda_e}{3000} \right)$$

Surface Load - The wing in conventional airplane mode flight must have a lift equal to the aircraft weight times its load factor plus the balancing tail load, normally a down load.

$$L_w = W_g N_z + L_H$$

The wing weight provides an inertia relief load, reducing the bending moments on the wing. An inertia relief factor is introduced since the load distribution and the wing weight distribution are not identical. Using the basic beam analysis model with a uniform load distribution and a triangular bending material weight distribution, an inertia relief integration factor of 1/2 is obtained for the wing weight.



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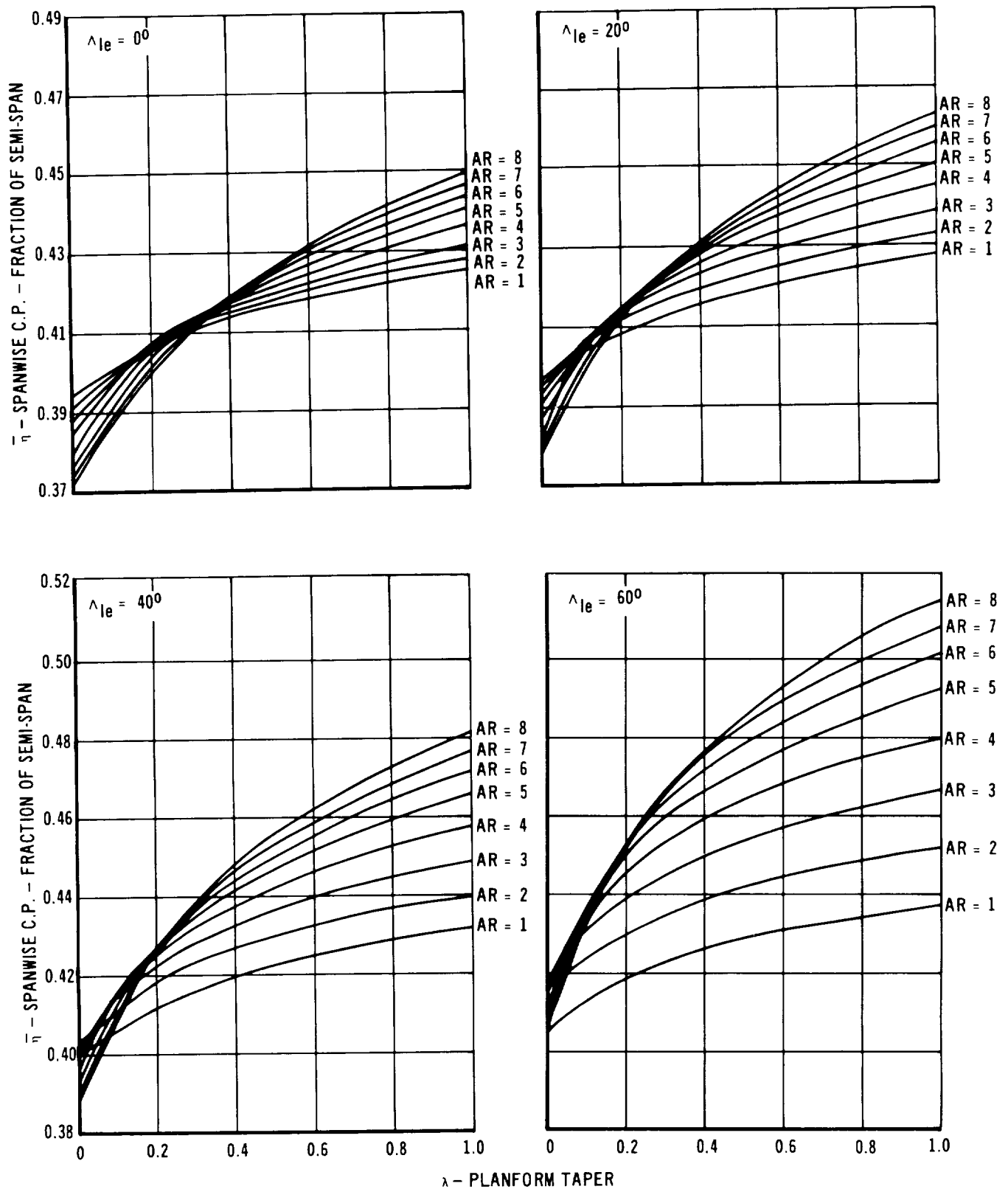


FIGURE 3.1-1 SPANWISE LOADING (RAE NO. 6403)

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The wing load is therefore:

$$L_w = (W_g - 1/2 W_w) N_z \pm L_H$$

Tail, gust, or ascent loads on the wing are input. If ascent loads are critical, as may be the case for Shuttle, the surface load may be input in one of three ways:

(1) the total wing load, as calculated outside the program, may be input in place of  $(W_g N_z \pm L_H)$ .

(2) an equivalent pressure over the wing ( $\Delta p_{Sw}$ ) may be input in place of  $(W_g N_z \pm L_H)$ .

(3) an equivalent load factor ( $N_z$ ) may be generated outside the program and used.

Body Lift - The method presented applies only to wings without fuselages, nacelles or tip tanks. At low angles of attack, the effect of the fuselage or nacelle is probably not critical. Thus, body lift is calculated directly from the method outlined in Reference (F). The loading at the centerline ( $\eta_o$ ) and at the wing/fuselage attachment ( $\eta_f$ ) is calculated as follows:

$$\frac{CC_L}{\bar{CC}_L} = F \eta \bar{\eta} + G ( ) + H ( )$$

where

$$F (\eta \bar{\eta}) = (3.395 - 5 \bar{\eta}) \sqrt{1 - \eta^2} + (20 \bar{\eta} - 8.488) \eta^2 \sqrt{1 - \eta^2}$$

$$G (\eta) = (AR \tan \Lambda \text{ te}) \left[ -0.01484 (1 - 6.666 \eta + 7.316 \eta^2) \sqrt{1 - \eta^2} \right]$$

$$H (\eta) = (AR - 4) (1 + 3.5 \tan \Lambda \text{ te}) \left[ 0.003 (1 - 14.5 \eta^2 + 21 \eta^4) \sqrt{1 - \eta^2} \right]$$

Note if  $AR < 4$ ,  $H (\eta) = 0$

The load carried on the body is calculated as the average loading times body span.

C.P. of Exposed Surface Lift - The body lift c.p. is calculated assuming a straight line variation between lift at  $\eta_o$  and  $\eta_f$ . Knowing the c.p. of the total lift, the c.p. of the exposed surface lift ( $\bar{\eta}_{ex}$ ) can be calculated. Solving and referencing  $\bar{\eta}_{ex}$  to the exposed span.

$$\bar{\eta}_{ex} = \left[ \frac{L \bar{\eta} - L_f \bar{\eta}_f - L_{ex} \bar{\eta}_f}{L_{ex}} \right] \frac{b}{b_{ex}}$$

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The bending moment at the wing fuselage attachment is:

$$M = L_{ex} \frac{\bar{\eta}_{ex}}{2} \frac{b_{ex}}{2}$$

Load Distribution on Exposed Surface - The calculation of loading across the exposed span by the method of Reference (E) does not lend itself to simple equations. Sufficient accuracy for preliminary estimates is obtained by a uniform distribution times a factor ( $k_{lcp}$ ) that produces the same root bending moment as calculated above. The c.p. of the uniform distribution airload is:

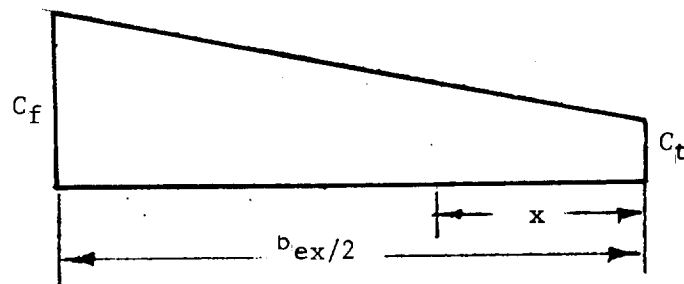
$$\bar{\eta}_{un} = \frac{1}{3} \left( \frac{2\lambda' + 1}{\lambda' + 1} \right)$$

where  $\lambda'$  is the planform taper ratio of the exposed surface -  $C_t/C_f$

The load distribution factor,  $k_{lcp}$  is simply

$$k_{lcp} = \frac{\bar{\eta}_{ex}}{\bar{\eta}_{un}}$$

The bending moment across the exposed span is derived as follows:



$$\text{The loading at } x = \Delta P \left[ C_t x + (C_f - C_t) \frac{x^2}{b_{ex}} \right]$$

$$\text{where: } \Delta p = \frac{L_{ex}}{S_{ex}} = \frac{2 L_{ex}}{b_{ex} C_f (1 + \lambda')}$$

The moment along the span is:

$$\begin{aligned} M_x &= k_{lcp} \Delta p \left( C_f \lambda' \frac{x^2}{2} + \frac{1}{2} (C_f - C_t) \frac{x^3}{3 b_{ex/2}} \right) \\ &= k_{lcp} \frac{2 L_{ex}}{b_{ex} C_f (1 + \lambda')} \left( \frac{C_f \lambda' x^2}{2} + \frac{C_f (1 - \lambda') x^3}{3 b_{ex}} \right) \end{aligned}$$

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expressing the distance along the span as a fraction:

$$\eta = \frac{x}{b_{ex}/2}$$

where  $\eta = 0$  at the tip

$\eta = 1$  at the wing fuselage attachment

$$M = k_{lcp} \frac{L_{ex}}{2} \frac{b_{ex}}{2} \frac{1}{3} \left\{ \frac{3\lambda' \eta^2 + (1 - \lambda')}{1 + \lambda'} \eta^3 \right\}_{0}^{1.0}$$

The moment at the root is:

$$M = k_{lcp} \frac{L_{ex}}{2} \frac{b_{ex}}{2} \frac{1}{3} \left( \frac{2\lambda' + 1}{\lambda' + 1} \right)$$

Sweepback and Carrythrough - A swept surface is evaluated in the same manner as a straight wing except, that structural span replaces aerodynamic span in the calculation of bending moment and the integration is performed along the structural span. Unless known, use the 0.50 chord line( $\theta$ ) as the structural axis. The structural span is  $b_{ex}/2 \cos \theta$ .

The carrythrough is assumed to be a straight, constant-thickness section through the body. The vertical shear is reacted at the wing fuselage attachment, thus, the carrythrough bending moment is constant and is based on aerodynamic span.

## 3.1.3 Section Bending Loads

Surface Thickness - The thickness along a span with a straight taper is:

$$h_x = \frac{h_f}{b_{ex}/2} \left[ m' \frac{b_{ex}}{2} + (1 - m') x \right]$$

where:

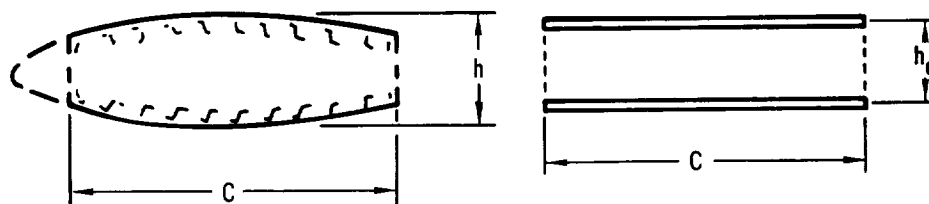
$$m' = h_t/h_f$$

$$h_f = \frac{h_r}{b} \left( mb + (1 - m) b_f \right)$$

Effective Thickness - The analysis model assumes all bending loads are carried in the cover skins. The wing structure is considered a two flange beam with the centroids of the flanges separated by the distance,  $h_e$ .

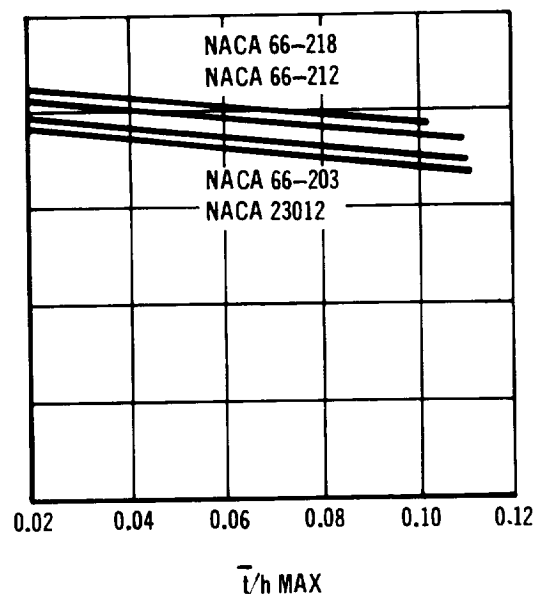
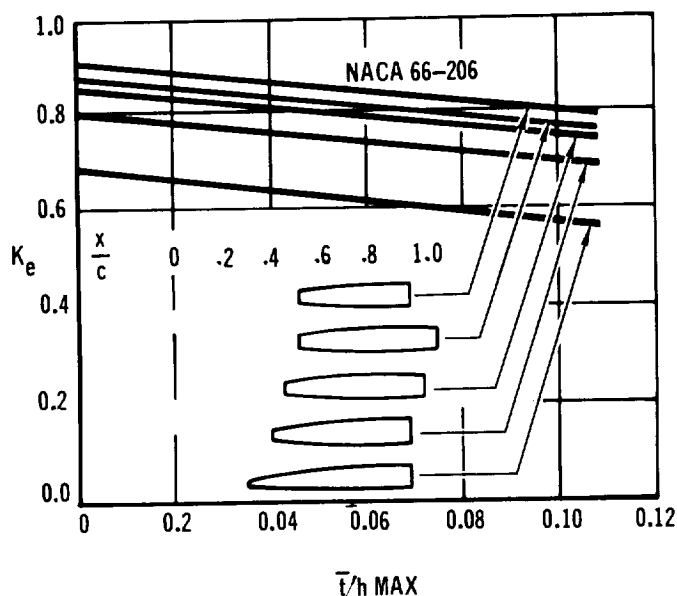
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REPRESENTATION OF WING BY EQUIVALENT TWO FLANGE BEAM

The ratio between the effective depth ( $h_e$ ) and the maximum depth ( $h$ ) is  $k_e$ . Shanley has investigated the effective depth factor variation with length and location of the box, and the thickness of the flange material for several airfoils (Reference (D)).



A nominal  $k_e$  value of 0.8 is used. This should be reevaluated for any new class of surfaces being examined and modified as required.

Cap Loads - The cap load ( $P_x$ ) at any section is obtained by dividing the moment ( $M_x$ ) by the thickness ( $h_x$ ).

$$P_x = \frac{M_x}{h_x}$$

$$P_n = \frac{k_{lcp} \frac{L_{ex}}{2} \frac{b_{ex}}{2 \cos \theta}}{h_f [m' + \frac{1}{(1 - m') \eta}]} \left\{ \frac{1}{3} \left[ \frac{2\lambda' \eta^2 + (1 - \lambda')}{1 + \lambda'} \right] \eta^3 \right\}$$

At the wing-fuselage intersection,

$$P_f = \frac{k_{lcp}}{h_f} \frac{L_{ex}}{2} \frac{b_{ex}}{2 \cos \theta} * \frac{1}{3} \left( \frac{1 + 2\lambda'}{1 + \lambda'} \right)$$

3.1-11

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3.1.4 Structural Model Bending Material

Cover Loads - The cover skins of an aerodynamic surface are usually subjected to longitudinal compression from spanwise bending, lateral compression from chordwise bending, and shear from torque. A rapid and logical method of obtaining and interacting the failure stresses from the three loadings is not known. AEROSURF assumes the spanwise bending stresses are critical and the effects of torque and chordwise bending can be neglected in establishing the weight equations.

Cover Skin Allowable - For the weight equations, the cover skin allowable stress is determined from the analysis of a single skin, open-face corrugation shell discussed in the appendix. This concept is chosen for ease of analysis and for the belief that the desired thickness-to-load relationship is reasonably typical for most structural configurations.

The smeared skin thickness ( $\bar{t}$ ) or unit weight ( $\bar{w}$ ) is computed for various unit loading intensities ( $N_x$ ), and plotted for the specific material and temperature under consideration. Straight-line approximations of the curves are developed following the approach of Shanley, Reference (D). The equations have the form of:

$$\frac{\bar{w}}{\rho_{144}} = \bar{t} = C_B + \frac{N_x}{F_A}$$

where:  $C_B$  is the intercept value or "shell" weight,

$F_A$  is an artificial allowable stress for the unit load, and

$N_x$  is the load intensity in lb/in.

The  $C_B$  term has a direct relationship to column length (rib spacing for cover skins), as shown in Figure 3.1-2. For a typical aluminum alloy and a reference rib spacing of 20 inches:

$$\bar{w} = 0.684 a_i + \frac{N_x}{56500} (0.10) (144)$$

where  $\bar{w}$  is expressed in lb/ft<sup>2</sup>.

Note that a good fit is obtained for loadings from 1000 to 15000 lb/in, and rib spacing from 10 to 60 in. In developing the equations, consideration is given to insuring that  $C_B$  is equal to or greater than minimum gage, and that  $F_A$  does not exceed  $F_{tu}$ . In correlations with existing aircraft where the particular alloy is not known, values of  $C_B = 0.70 a_i$  and  $F_A = 60,000$  are used for aluminum, and  $C_B = 1.05 a_i$  and  $F_A = 128,000$  are nominal values for titanium.

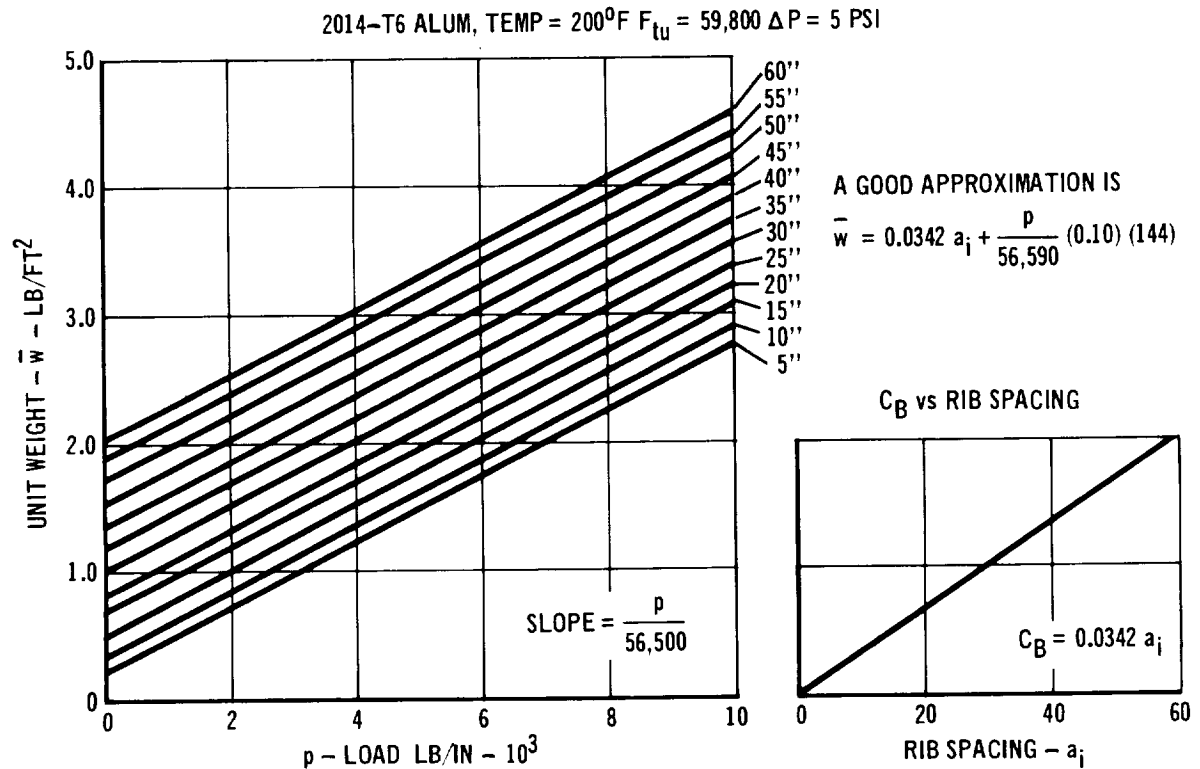


FIGURE 3.1-2 SHELL MODEL UNIT WEIGHT VS RUNNING LOAD AND RIB SPACING

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Compression vs. Tension Cover - The beam model places the upper cover in compression and the lower cover in tension. It could be anticipated that the lower cover with the higher tension allowables would be lighter than the compression cover. The detail weight statements of a variety of aircraft fail to show this trend. In fact, the covers are similar in weight with no consistent pattern as to which is the heavier.

COMPARISON OF WING BOX COVER WEIGHTS

<u>FIGHTERS</u>	<u>UPPER COVER</u>	<u>LOWER COVER</u>	<u>REFERENCE</u>
F-105F	943	839	(d)
A3J-1	1,577	1,526	(d)
F-5A	216	226	(d)
F-101B	954	1,044	(d)
F-104F	258	252	(d)
F-100D	876	854	(d)
F-4D	935	1,006	(d)
<u>BOMBERS/CARGO/TRANSPORTS</u>			
B-47B	4,610	4,698	(d)
B-52A	11,123	11,251	(d)
B-58A	3,038	2,841	(d)
C-135A	6,314	5,849	(d)
C-133B	6,682	7,053	(d)
C-130F	2,654	2,441	(d)
BAC-747	17,514	21,472	
C-5A	15,560	17,215	

Reasons why the cover weights are similar may be:

- o fasteners and other cutouts reduce the effective area on the tension surface.
- o gust, inverted flight, taxi, and other loadings not considered by the model place compression loads in the lower surface.
- o manufacturing considerations.

AEROSURF considers the weight of the lower "tension" cover equal to the upper "compression" cover.



### 3.1.5 Equations for Bending Material -

Basic Beam Model - Section 3.1.1 shows the weight of a basic beam is:

$$W = \rho \int_0^{\ell} A_x dx$$

$$= \frac{1}{3} \frac{\rho L \ell^2}{f h}$$

Combined Planform and Thickness Taper - A conventional aerodynamic surface is tapered in both planform and thickness. The integration factor for the combined effect is derived as follows:

$$W = \frac{2 \rho}{f} \int_0^{\ell} \frac{M_x}{h_x} dx$$

o the moment is:

$$M_x = \Delta p C_f \left[ \lambda' \frac{x^2}{2} + \frac{(1 - \lambda') x^3}{6 \ell} \right]$$

o the thickness is:

$$h_x = \frac{h_f}{\ell} [m' \ell + (1 - m') x]$$

solving:

$$W = \frac{\rho L \ell^2}{3 f h_f} (k_{\lambda m})$$

o The integration factor,  $k_{\lambda m}$ , is presented in Figure 3.1-3.

Equation Development - The structural model unit weight is:

$$\bar{w} = \bar{t} (0.10)(144) = C_B + \frac{P}{F_A} (0.10)(144)$$

The shell portion ( $C_B$ ) is independent of load and a function only of rib spacing ( $a_1$ ). The second term, load/allowable, is the same as the  $A_x$  term of the basic beam model. The  $\bar{t}$  of the second term is simply  $A_x/C_x$ .

The shell portion is a function of rib spacing. Some studies, including References G and H, suggest the optimum rib placement is near  $a_1 = h_x$ , and that the total weight is relatively insensitive to rib spacing. AEROSURF uses

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rib spacing as constant along the structural axis with spacing equal to  $h$  at  $0.2 b_{ex}/2$  and minimum spacing of 12 in.

The carrythrough weight equation is:

$$W = \rho A b_f = \frac{2 \rho M}{h_f f} b_f$$

where:

$$M = k_{lcp} \frac{L_{ex}}{2} \left[ \frac{b_{ex}}{2} \frac{1}{3} \frac{(2\lambda + 1)}{(\lambda + 1)} \right]$$

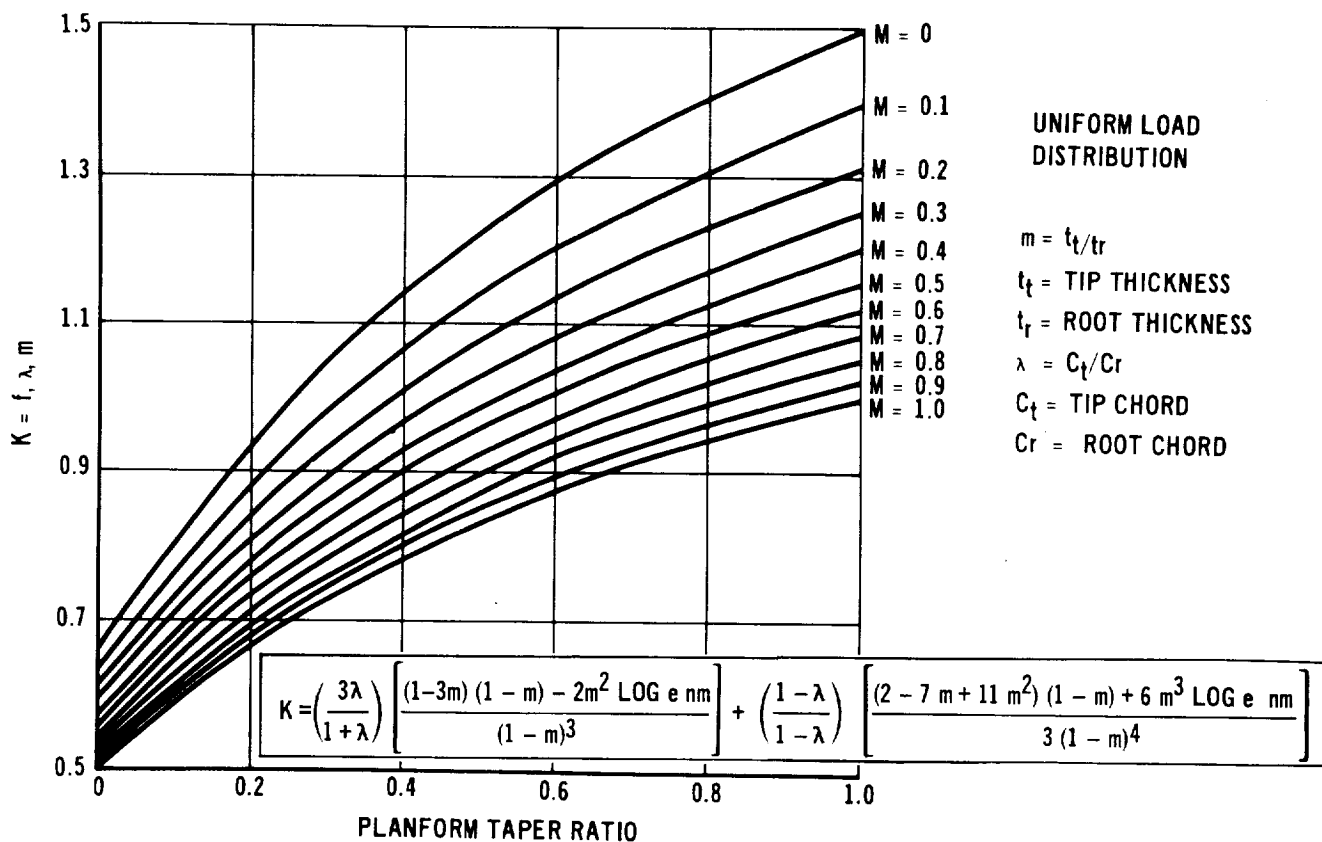


FIGURE 3.1-3 PLANFORM & THICKNESS RATIO INTEGRATION FACTOR - K

## 3.1.6 Shear Material

Structural Model - The structural model has the vertical shear carried by two spars. Torque is not considered, and the spars do not contribute to cover stability.

Shanley (Reference D) has developed a model for shear resistant webs similar to that developed for the cover skins.

$$A = 0.003 h^2 + S/21,500$$

where:

$S$  = vertical shear

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A similar expression is developed for AEROSURF, using the tension field analysis of Reference (I). The allowable web shear stress ( $\tau$ ) is expressed as a function of a structural index.

$$\tau = f(100) \sqrt{\frac{E}{F_{tu}^3} \frac{S}{h^2}}$$

At low load values,  $\tau$  approaches  $0.383 F_{tu}$ .

The stiffener area ( $A_{stiff}$ ) to web area ratio is a function of the index ( $S/h$ ), with a range of 0.3 to 0.6, representing the most efficient stiffener/web ratio for typical loadings. The weight/load curves developed from Reference I for typical aluminum and titanium webs are shown in Figure 3.1-4.

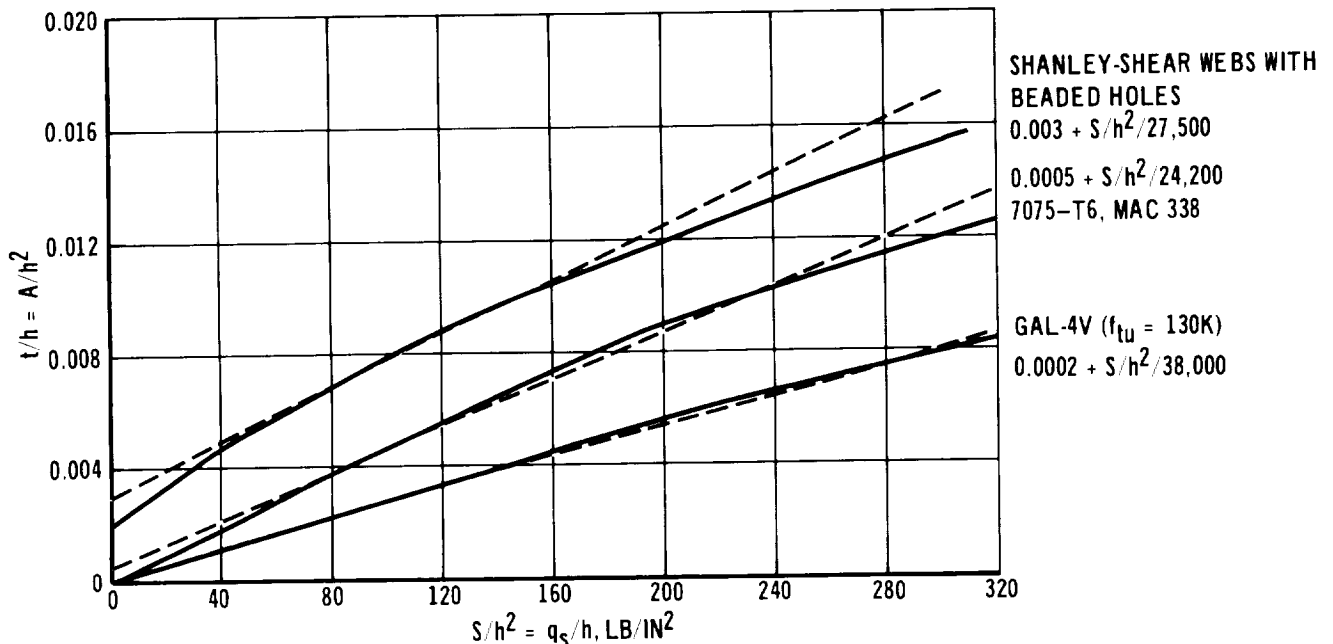


FIGURE 3.1-4 UNIT WEIGHT OF SHEAR WEBS

The intercept of the shear curve does not reflect a minimum gage web. If the specific  $\bar{t}/h = C_s + \frac{S/h^2}{\lambda_A}$  relationship has not been developed, use:

$$\text{titanium } C_s = 0.0002, \tau_A = 0.29 F_{tu}, t_{min} = 0.02$$

$$\text{aluminum } C_s = 0.0005, \tau_A = 0.29 F_{tu}, t_{min} = 0.03$$

Loading - The area of two shear webs at a section is:

$$A_x = 2 t_{min} (0.8 h_x) + 2 C_s (0.8 h_x) + S_x / \tau_A$$

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where:

$$h_x = \frac{h_f}{b_{ex}/2} \left[ m' \frac{b_{ex}}{2} + (1 - m') x \right]$$

$$S_x = \Delta p C_f \left[ \lambda' x + (1 - \lambda') x^2 / b_{ex} \right]$$

$$\Delta p = \frac{2 L_{ex}}{b_{ex} C_f (1 + \lambda')}$$

The load distribution factor  $k_{lcp}$  is introduced to provide an artificial measure of the actual load distribution.

Equation Development - Shear material equations are developed in the same manner as the bending material equations.

$$W = 2 \rho \int_0^{\frac{b_{ex}}{2 \cos \theta}} A_x dx$$

o the minimum gage term is:

$$\rho t_{min} 0.8 h_f \left( \frac{b_{ex}}{\cos \theta} \right) (m' + 1)$$

o the shell material (shear curve intercept) term is:

$$\frac{2}{3} \rho C_s (0.8 h_f)^2 \frac{b_{ex}}{\cos \theta} (m'^2 + m' + 1)$$

o the shear material term is:

$$\frac{\rho k_{lcp} L_{ex} b_{ex} (2 \lambda' + 1)}{6 \tau_A \cos \theta (\lambda' + 1)}$$

The model considers only vertical shear loads. Thus, there is no shear load in the carrythrough. An arbitrary closure web, equal to the bending shell ( $C_B$ ), provides an allowance for torque and loads not accounted for in the model.

## 3.1.7 Ribs -

Structural Model - The bending and vertical shear loads are taken in the cover and two spar webs of the multirib torque box. The ribs in an actual surface may be designed by one or more of many conditions. Reference G is used as a guide for the rib model. Full depth ribs are assumed.

Two loads are considered in rib sizing:

- o flexure induced crushing load from spanwise bending curvature, and
- o stiffness to develop the column strength of the cover.

The flexure-induced crushing load on the rib is:

$$N_{n_x} = \frac{2 p_x^2 a_i}{E t_{c_x} h_x}$$

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The stiffness required to attain the column strength of the panel obtained from Reference (G) as:

$$\psi_{rib} = \frac{E_r \bar{t}_{ri}}{h_i}$$

Required stiffness is :

$$\psi_{req} = \frac{C_R E_c I_c}{C_x a_i^3}$$

Where  $C_R$ , a stiffness parameter, equals 67.5 when upper and lower panel rigidity is equal.

$$P_{CR} = \frac{\pi^2 E_c I_c}{a_i^2}$$

but

$$P_{CR} = \frac{M_x}{h_x}$$

Thus, for stiffness to obtain column strength of the cover:

$$\bar{t}_{R_x} = \frac{67.5 M_x}{\pi^2 E_r C_x a_i}$$

Equation Development - The rib weight equation is:

$$W_R = 2 \rho \int_0^{b/2} \frac{\bar{t}_{rx} \cos \theta}{h_x c_x a_i} dx$$

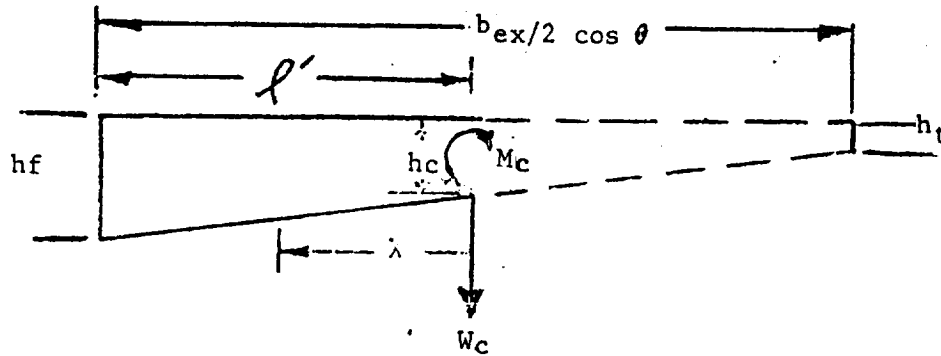
where  $\bar{t}_{rx}$  = the larger of the stiffness or the load requirement. The total rib weight is calculated as the average unit rib weight per inch times the span. The rib weight at the fuselage intersection is calculated from the derived  $\bar{t}_{rx}$ . The tip rib  $\bar{t}$  is considered equal to  $C_B$  of the shell material.

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3.1.8 Concentrated Loads

Bending Relief - A concentrated weight will normally provide a relieving load to the surface. The weight increment is derived using the basic bending beam model.



The weight, per side, is:

$$W_{rel} = \int_0^{\ell} \rho A_x dx$$

$$A_x = \frac{2 W_c x}{f h_f m'' \ell' + (1 - m'') x} \cdot \frac{\ell'}{\ell'}$$

where:

$$h_c = h_f \left[ 1 - \frac{\ell'}{b_{ex}/2 \cos \theta} (1 - m) \right]$$

$$m'' = h_c / h_f$$

Solving:

$$W_{rel} = \frac{\rho W_c \ell'^2}{F_A \cdot 0.8 h_f} k_{m''}$$

where:

$W_c$  is the weight for both sides thus  $W_{rel}$  = both surfaces

$$k_{m''} = 2 \left[ \left( \frac{1}{1 - m''} \right) + \frac{m'' \ln m''}{(1 - m'')^2} \right]$$

The 10 percent factor for joints (JSF) is included as are the increments in the carrythrough and shear material. The effect on ribs and other allowances are considered small. The total relief term is:

Weight = (bending exposed + bending carrythrough + shear) JSF

$$W_{rel} = \left[ \frac{W_c \ell'^2}{F_A \cdot 0.8 h_f} k_{m''} + \frac{\rho W_c \ell' \cos \theta b_f}{F_A \cdot 0.8 h_f} + \frac{\rho W_c \ell'}{\tau_A} \right] 1.10$$

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Concentrated Moment - The weight increment for a surface including the added moment (fin) is determined as follows:

$$W = 2 \rho \int_0^{\ell'} A_x dx$$

$$= \frac{4 \rho M_c \ell'}{F_A \cdot .8 h_f} k_{mc}$$

where  $k_{mc} = \ln m'' / (m'' - 1)$

The carrythrough weight increment is:

$$W_{rel} = \frac{2 \rho M_c b_f}{F_A \cdot .8 h_f}$$

3.1.9 Allowances - The total wing structural weight will be different than the "optimum" weight defined by the prediction model. This difference is accounted for by two methods, (a) assessing reasonable values for known items that cannot be quantified by analysis, and (b) including an overall nonoptimum or contingency factor for the remaining weight difference, this factor being based on correlations to existing surfaces.

Joints - On any built-up structure weight penalties are incurred for joints. Aircraft detail weight statements breakout the identifiable elements of joints, splices, and fasteners (JSF). Reference (J) data and other detail weight statements show the following percentage of torque box weight for JSF.

<u>Aircraft</u>	<u>Percent</u>	<u>Aircraft</u>	<u>Percent</u>	<u>Aircraft</u>	<u>Percent</u>
B47B	6.3	C-135A	22.1	F-104F	5.9
B-52A	7.9	C-133B	6.8	F-100D	13.1
B-58A	8.8	F-105F	6.2	F-4D	7.9
B-36A	8.9	A3J-1	8.8	A-3D-2	9.3
F-8E	7.8	X-15A	6.3	C-5A	8.6
C-119H	13.4	F-5A	10.0	DC-8-63	10.1
KC-130F	8.9	F-101B	15.7	DC-10-10	7.3

No logical trend with any geometry or loading parameters was found. Note that differences in weight grouping may be significant and the values listed may be biased, to some degree, to the low side since elements not readily identifiable,

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such as integral doublers, thicker skins or webs, "nonoptimum" load paths, overlaps, etc., are not normally included in the JSF grouping. Ten percent is added to the torque box weight for joints.

Standard Gages - Modern aircraft use extensive machining methods, therefore, only a small factor is anticipated for the use of standard gages and not tapering all elements to absolute strength requirements. A thickness of 0.005 in. per surface appears reasonable for aluminum structure to account for this manufacturing problem. Since titanium and steel will be subjected to even more exotic machining a unit weight of  $0.14 \text{ lb/in}^2$  is included for all materials.

Simplified Model - The loading condition assumed in the analysis model considers only one flight condition. The multiple loadings on an actual surface, HAA, LAA, Landing, torque, etc., will increase the loads derived by the analysis model on some or all structural elements. Bending material will be affected somewhat, shear webs and ribs to a greater extent. An arbitrary 10 percent in bending structure, and 20 percent in shear structure and ribs is included to reflect the multiple load conditions.

Contingency - Correlation with contemporary aircraft data shows the prediction model defined a weight that is 25 percent less than actual surface weight. A contingency factor is added to the manual to account for this weight. Comparison of the contingency factor to various geometric and loading parameter failed to show any logical trends. Thus there is confidence that the model does reflect actual variations and that realistic data is obtained for designs and loadings that may represent significant extrapolation from the contemporary aircraft.

The correlation data are presented graphically in Figure 3.1-5. Table 3.1-1 presents the weight data and basic geometric data. For the correlation to aircraft the Leading Edge Structure and Trailing Edge Structure are estimated from the following empirical equations:

$$\text{leading edge WLE} = 3.38 \left( \frac{0.001 \text{ Wg Nz}}{\text{SG}} \right)^{0.3} \quad \text{SLE}$$

$$\text{trailing edge WTE} = 1.87 \left( \frac{0.001 \text{ Wg Nz}}{\text{SG}} \right)^{0.2} \quad \text{STE}$$

These equations yield unit weights (pounds/projected areas) of 2.5 to 3.5 psf for leading edges, 1.5 to 2 psf for trailing edges. For materials other than aluminum, these structures are assumed to be lightly loaded structure and ratioed by the unit weight of the new material to unit weight of aluminum at a 500 pounds per inch loading as determined by the SHELL program.



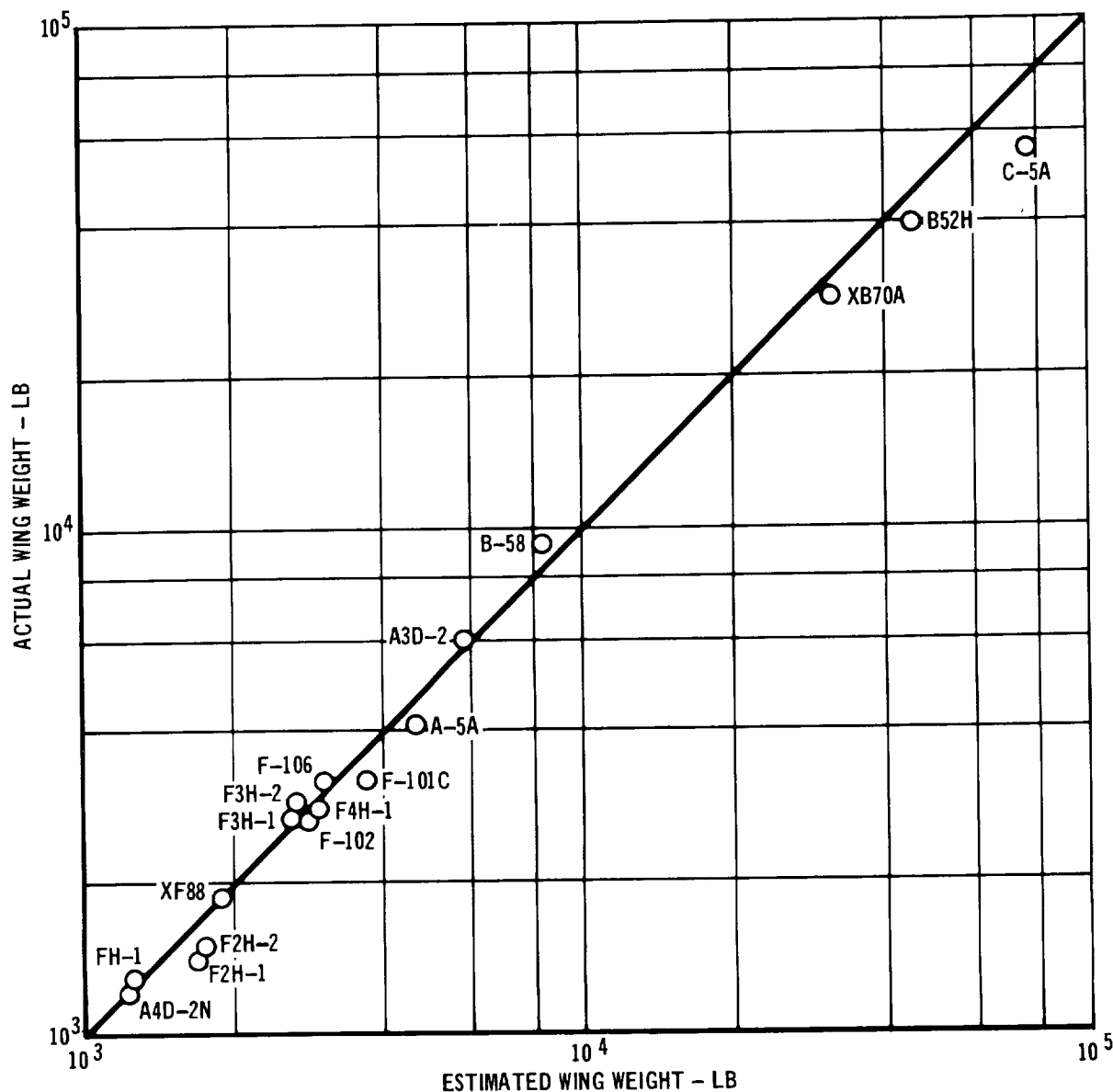


FIGURE 3.1-5 AEROSURF PREDICTED WEIGHT VS ACTUAL WEIGHT  
(Wing Less Control Surfaces)

Table 3.1-2 lists the actual and estimated weights of 19 airplane wings used in the correlations. Table 3.1-3 is the input file for the NR Orbite wing and Table 3.1-4 is the resulting output wing weight. Table 3.1-5 is a detail listing of the AEROSURF program.

The following is a listing of the fortran symbols along with their corresponding units and description.

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<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
AICP	ND	Control Surface HL Fraction of Chord
AILP	ND	Control Surface Fraction of Exposed Span If AICP = 0 Area of Control Surface
AR	ND	Aspect Ratio (Wing)
B	Feet	Span
BCML	In	Location of Concentrated Moment Input to Orbiter Centerline
BCT	Ft	Span of Carrythrough
BLP1	In	Location of Concentrated Weight Input (1) to Orbiter Centerline
BLP2	In	Location of Concentrated Weight Input (2) to Orbiter Centerline
CB	Lb/Ft <sup>2</sup>	Shell Material Intercept
CF	Ft	Chord at Fuselage intersection
CLE	ND	Leading Edge Fraction of Chord
CML	Lb	Concentrated Moment Input
CR	Ft	Chord at Root
CS	ND	Shear Web Material Intercept
DELP		Equivalent $\Delta p$ of Critical Loading (Either WG*NZ or DELP, or both, must be entered for wing)
EMODU	Lb/Ft <sup>2</sup>	Modulus of Elasticity of Torque Box Material
ETA WNG	ND	CP of Surface Load
FA	Lb/In <sup>2</sup>	Artificial Allowable Covers
FCP	ND	Flap Chord/Wing Chord
FG	Lb	Main Gear Vertical Reaction

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<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
FLP	ND	Flap hinge line length/Exposed Span
GLM	Inches	Length Main Gear
KEAS	Lb/Ft <sup>2</sup>	Unit Pressure on Elevon
KP	ND	Integration factor - planform and thickness taper
LAMB	ND	Planform Taper Ratio
LAMP	ND	Planform Taper Ratio - exposed
LE	Lb	Weight of Leading Edge
LH	Lb	Horizontal Tail Load
M	ND	Tip Thickness/Root Thickness
MP	PSF	Tip Thickness/Thickness at fuselage
NZ	ND	Ultimate Vertical Load Factor
PTBXC	%	Area of Carrythrough/Area Buried (THEOR.)
PTBXE	%	Area of Torque Box/Area Exposed
Q	Lb/Ft <sup>2</sup>	Orbiter dynamic pressure
RBM	Ft Lb	Root Bending Moment
RHO	Lb/In <sup>3</sup>	Density Material, torque box
SEXP	Ft <sup>2</sup>	Exposed Surface Area
SFLPLE	Ft <sup>2</sup>	Area Leading Edge Flap
SFLPTE	Ft <sup>2</sup>	Area Trailing Edge Flap
SG	Ft <sup>2</sup>	Aero Ref. Wing Area
SL	Lb	Exposed Surface Load
SLRATI	ND	Fraction of Load on Body
SMGDR	Ft <sup>2</sup>	Area of Main Landing Gear Doors

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<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
SSB	Ft	Area Speed Brakes - Spoilers
SSLAT	$Ft^2$	Area, Slats
STE	$Ft^2$	Area of Trailing Edge (Calculated if O. Input)
TAU	$Lb/In^2$	Shear Allowable
TEMP	$^{\circ}F$	Design Temperature, torque box (Ref. info. Not used in calc.)
THETA	Deg	Sweepback Angle @ 50% Chord
TMIN	In	Minimum Thickness of Spar Webs
TOCR	ND	Thickness Ratio at Root
TOCT	ND	Thickness Ratio at Tip
UFLPLE	$Lb/Ft^2$	Unit Weight, Leading Edge Flap
UFLPTE	$Lb/Ft^2$	Unit Weight, Trailing Edge Flap
ULE	$Lb/Ft^2$	Unit Weight of Leading Edge
USB	$Lb/Ft^2$	Unit Weight Speed Brakes - Spoilers
USLAT	$Lb/Ft^2$	Unit Weight of Slats
UWAIL	$Lb/Ft^2$	Unit Weight, control surface shell If AICP = 0 Unit Weight of Control Surface
UWW	$Lb/Ft^2$	Unit Wing Weight
WAILDR	Lb	Weight Aileron Drive Rib
WAILH	Lb	Weight Aileron Hinges
WAILS	Lb	Weight Aileron Shell
WBREL	Lb	Weight Bending Relief
WC1	Lb	Concentrated Weight Input (2)
WC2	Lb	Concentrated Weight Input (2)
WLE	$Ft^2$	Wetted Area of Leading Edge
WSWPKR	Lb	Weight Sweepback Kick Rib

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TABLE 3.1-1  
COMPARISON OF REPORTED WEIGHT ELEMENTS TO ESTIMATED WEIGHTS

AIRCRAFT STATISTICS - AEROSURF WING CORRELATIONS															
	FB-1	F2H-1	F2H-2	F3H-1	F3H-2	F4H-1	F4H-2	F4H-3	F4H-4	F4H-5	F4H-6	F4H-7	F4H-8	F4H-9	F4H-10
GEOMETRY															
AR - ASPECT RATIO	6.01	5.59	5.59	2.81	2.42	2.74	4.48	4.48	6.47	2.91	4.01	2.08	8.56	2.10	7.75
ECT - BODY SPAN	3.00	3.00	3.00	4.20	4.20	5.20	7.70	7.70	2.91	8.70	8.20	5.50	9.15	4.17	20.00
LAME - TAPER RATIO	4.287	4.080	4.080	5.230	5.230	5.230	5.230	5.230	5.230	5.230	5.230	5.230	5.230	5.230	5.230
TOUR - ROOT T/C	1.1700	1.1200	1.1200	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860	1.0860
TOUR - TIP T/C	1.1100	0.9900	0.9900	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640	0.8640
ES - GROSS AREA	277	311.4	311.4	442	516	538	351	812	260	700	698	198	1000	1543	6297
THICK - SPAN .50 C	7.147	8.179	8.179	40.690	35.448	32.054	28.690	30.266	20.55	20.050	24.824	6.856	32.878	37.81	22.15
PTBAC - 1 TB EXP	54	47	47	47	46	47	52	38	40	503	45	452	47	45	46
CLE - COEFF L.E. AREA	229	216	216	1179	1351	147	537	388	222	5	13	50	173	152	613
STE - AREA T.E.	37	61.40	61.40	17.60	23.0	14.0	57.2	84.0	31.10	117.43	6.00	13.02	6.90	1213	496.58
LOADING															
W - GROSS WEIGHT	9800	14000	14000	26000	26000	34500	16500	37000	12504	40953	25500	16400	34200	45000	53400
W - LOAN FACTOR	11.25	9.600	9.600	11.25	11.25	9.75	11.00	11.00	10.90	10.90	11.00	11.00	9.00	9.00	3.46
W - TAIL LOAD	13600	15070	15070	20280	29200	61600	16600	50100	23100	67700	21000	23000	25000	109800	120000
W - UNIT 4IN. WT	6.30	6.25	6.25	9.05	8.53	7.62	6.26	9.24	10.74	7.13	4.2	5.61	4.72	9.40	13.2
W - SHAN - LOAN #1	420	620	620	1010	1040	1070	710	8.3	13.71	7.20	890	0	1760	16.90	39.7
W - SHAN - LOAN #2	1320	2420	2420	3.1	3.1	3.1	3.1	3.1	3.1	3.1	7.10	0	7.10	32.0	61.8
W - SHAN - LOAN #3	1320	2420	2420	3.1	3.1	3.1	3.1	3.1	3.1	3.1	7.10	0	7.10	32.0	61.8
MATERIAL															
RE - DENSITY	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
DE - DENSITY INTERCEPT	170	170	170	170	170	170	170	170	170	170	170	170	170	170	170
CS - SHEAR INTERCEPT	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
FA - FAN ALLOWABLE	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
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PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
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PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
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PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420	2420
PROB - B	2420	2420	2420	2420	2420	2420	2420	2							

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TABLE 3.1-2  
ESTIMATED WEIGHT VS ACTUAL WEIGHT

AEROSURF PREDICTED WEIGHT VS ACTUAL WEIGHT																				
		FH-1	F2H-1	F2H-2	F3H-1	F3H-2	F4H-1	XF88	F-101C	A3D-2	A4D-2N	A-5A	F-102	F-104	F-105	F-106	B-52H	B-58A	C-5A	XB70
REPORTED WEIGHT (LESS CONTROL SURFACES)		1807	2068	2320	4048	4400	4056	2243	3621	8717	1587	5248	3330	1231	4969	3651	44476	12156	81782	31133
BASIC & SECONDARY STRUCTURE		1584	1796	2060	3350	3535	3389	1956	3232	7204	1354	4421	2990	940	4352	3324	40287	11021	61384	29292
SPECIAL INCREMENTS		(311.09)	(370.98)	(594.87)	(674.25)	(680.03)	(639.39)	(-99.52)	(-104.76)	(1133.87)	(104.29)	(341.89)	(265.76)	(48.00)	(45.83)	(165.59)	(1606.30)	(1712.26)	(6333.2)	(918.0)
PROPULSION SYSTEM PROV		70.56	137.59	138.33	62.08	62.08	45.61	26.40	133.02	161.40	34.54	81.22	88.76	--	85.68	107.59	1251.60	363.26	3705.0	180.0
EXPANDED ROOT THICKNESS		-53.81	-124.38	-124.34	--	--	--	-205.92	-523.78	--	--	--	--	--	-266.50	--	--	--	--	--
WING FOLD		282.42	357.77	434.88	438.17	443.95	284.81	--	504.47	--	--	195.67	--	--	--	--	--	--	--	--
CATAPULT		11.92	--	--	--	--	41.97	--	0	17.45	--	--	--	--	--	--	--	--	--	738.0
TIP TANK/EXT STORES		--	--	146.00	29.00	29.00	30.00	80.00	--	126.00	52.29	--	177.00	--	55.70	30.00	--	--	--	--
SPECIAL FATIGUE/RIGIDITY		--	--	--	145.00	145.00	90.00	--	218.00	342.00	--	--	--	--	37.00	--	--	--	--	--
BLC/SPECIAL CONTROL PROV.		--	--	--	--	--	104.00	--	68.00	--	--	65.00	--	--	42.29	--	--	--	--	--
RAM AIR TURBINE		--	--	--	--	--	43.00	--	--	--	--	--	--	--	--	--	--	--	--	--
MISCELLANEOUS/FAIRINGS		--	--	--	--	--	--	--	--	--	--	--	--	48.00	--	28.00	--	1349.00	2628.2	--
TIP LDC GEAR		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	354.70	--	--	--
REFERENCE WEIGHT		1273	1425	1465	* 2676	2855	2750	1856	3127	6070	1250	4079	2724	892	4306	3158	38681	9309	55051	28374
AEROSURF WEIGHT (LESS CONTROL SURFACES)		1242	1681	1708	2629	2634	2941	1892	3689	5878	1232	4536	2860	1041	4136	3062	45326	8213	76706	31254

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TABLE 3.1-3  
WING INPUT

1000 NRSHTTLE  
2000 AR=2.19,BCT=17.5,LAMB=.21,TOCR=.09,TCT=.12,WLE=484.  
3000 SG=3220.,THETA=10.,PTRXC=.43,PTRXE=.594,CLE=.100,STE=0.  
4000 WG=215000.,NZ=3.75,LH=0.,UWW=0.,BLP1=0.,WC1=0.,BLP2=0.,  
5000 WC2=0.,BCM1=0.,CM1=0.,DELP=296.,KEAS=.68  
6000 RHO=.10,CB=.67,CS=.0005,FA=64394.,EMODU=10.E+6,  
7000 TAU=22320.,TMIN=.03,TFMP=70.,  
8000 AILP=1.0,UWAIL=1.75,AICP=.306,FLP=0.,FCP=0.,SFLPTE=0.,  
9000 UFLPTE=0.,SFLPLE=0.,UFLPLE=0.,SSB=0.,USB=0.,SSLAT=0.  
9500 ULE=1.60,USLAT=0.  
10000 FG=235000.,GLM=95.,Q=650.,SMGDR=190.,  
11000 \*

TABLE 3.1-4  
WING WEIGHT

ASPECT RATIO	=	2.2	EXPOSED AREA	=	2202.	FT2
AREA, GROSS	=	3220.	FT2	GROSS WEIGHT	=	215000.
TAPER RATIO	=	.2100	LOAD FACTOR	=	3.750	LB
ROOT T/C	=	.0900	PRESSURE	=	296.000	PSF
TIP T/C	=	.1200	BODY SPAN	=	17.5	FT
SPAN	=	84.0	FT	SWEEP ANGLE	=	10.0000
SURFACE LOAD	=	651837.9	LB	MATERIAL	=	NRSHTTLE
ROOT B.M.	=	4515091.	FT-LB	TEMPERATURE	=	70.
						DEG.F

ELEMENT	EXPOSED	CARRY-THRU
BENDING		
SHELL	1753.	586.
BENDING	1020.	748.
KICK RIB	44.	
BEND REL	0.	
SHEAR		
SHELL	228.	91.
SHEAR	485.	
RIBS	2243.	1074.
JOINTS	573.	250.
STD.GAGE	183.	61.
MODEL	648.	290.
SUBTOTAL	7178.	3101.
NON-OPT.	1794.	775.
SUBTOTAL	8972.	3876.
TOTAL TORQUE BOX		12848.
LEADING EDGE		774.
MAIN GEAR PROV		1202.
SURF CONT PROV		588.
FLAPS		0.
AILERONS		2352.
TRAILING EDGE		-0.
TOTAL WING		17764.

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TABLE 3.1-5  
AEROSURF LISTING

#LIST AEROFEB10

AEROFEB10 22:02 FEB 27, '73

```

1000$FIXED
2000      DIMENSION A(3)
3000      REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMP,MP,KP,KMPP,KMC,MPP
4000      COMMON AR,SG,LAMB,TCCR,TCT,BCT,THETA,WG,NZ,DELP,LH
5000      1,PTBXC,PTBXC,CB,RH2,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
6000      1,EMODU,WSWPKR,WBREL,WCI,W2,CMI,BLP1,BLP2,BCMI
7000      2,WLE,ULE,CSR,TMIN,G(30)
8000      COMMON/RWRW/FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
9000      1,FG,GLM,Q,SMGDR,GPRDV,STE,CSPRVD
10000     2,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
11000     COMMON/RWRHT/ELSC,ELCC,UEL,UES,ELB
12000     COMMON/RWRVT/RDC,RUDUL,URS
13000     NAMELIST
14000     1 AR,SG,LAMB,TCCR,TCT,BCT,THETA,WG,NZ,DELP,LH,PTBXC
15000     2,PTBXC,CB,RH2,FA,CS,TAU,TEMP,UWW,CSR,TMIN
16000     3,ULE,FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
17000     4,ELSC,ELCC,UEL,UES,ELB,RDS,RUDUL,URS,WLE,RDC
18000     5,EMODU,WCI,W2,CMI,BLP1,BLP2,BCMI
19000     6,FG,GLM,Q,SMGDR,STE
20000     7,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
21000^10   WRITE (108,900)
22000     READ (105,901,END=9999) J
23000     IF (J.EQ.0) GO TO 9999
24000     READ (J,999)(A(I),I=1,3)
25000     GO TO (20,30,40),J
26000^20   INPUT(1)
27000     CALL WING(J)
28000     GO TO 50
29000 30    INPUT(2)
30000     CALL HTAIL(J)
31000     GO TO 60
32000 40    INPUT(3)
33000     CALL VTAIL(J)
34000     GO TO 70
35000^50   WRITE (108,902)
36000     GO TO 80
37000^60   WRITE (108,903)
38000     GO TO 90
39000^70   WRITE (108,904)
40000^80   WRITE (108,905) AR,SEXP
41000     WRITE (108,906) SG,WG
42000     WRITE (108,907) LAMB,NZ
43000     WRITE (108,908) TCCR,DELP
44000     WRITE (108,909) TCT,BCT
45000     WRITE (108,910) B,THETA

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TABLE 3.1-5  
AEROSURF LISTING (Continued)

```

42000 WRITE(108,911) SL,A
43000 WRITE (108,912) RBM,TEMP
44000 WRITE (108,913) G(1),G(2)
45000 WRITE (108,914) G(3),G(4)
46000 WRITE (108,950) WSWPKR
47000 WRITE (108,960)WBREL
48000 WRITE (108,915) G(5),G(6)
49000 WRITE (108,916) G(7)
50000 WRITE (108,917) G(8),G(9)
51000 WRITE (108,918) G(10),G(11)
52000 WRITE (108,919) G(12),G(13)
53000 WRITE (108,920) G(14),G(15)
54000 WRITE (108,921) G(16),G(17)
55000 WRITE (108,922) G(18),G(19)
56000 WRITE (108,923) G(20),G(21)
57000 WRITE (108,924) G(22)
58000 WRITE (108,925) G(23)
59100 WRITE (108,965) GPRØV
59500 WRITE (108,970) CSPRØV
59900 GO TO (90,100,110),J
60000^90 WRITE (108,926) G(24)
61000 WRITE (108,927) G(25)
62000 WRITE (108,928) G(26)
63000 WRITE (108,929) G(27)
64000 GO TO 20
65000^100 WRITE (108,930) G(24)
66000 WRITE (108,931) G(25)
67000 WRITE (108,932) G(26)
68000 WRITE (108,933) G(27)
69000 WRITE (108,934) G(28)
70000 GO TO 30
71000^110 WRITE (108,935) G(24)
72000 WRITE (108,936) G(25)
73000 WRITE (108,937) G(26)
74000 WRITE (108,938) G(27)
75000 WRITE (108,939) G(28)
76000 GO TO 40
77000^599 FORMAT(3A4)
78000^900 FORMAT(1H1,10X,'WHAT DO YOU WISH TO RUN?'/10X
79000 1, '(0=STOP, 1=WING, 2=HØRIZØN. TAIL, 3=VERT. TAIL)'/10X
80000 2, 'THE INPUT FILE MUST BE ASSIGNED TO THE NUMBER YOU PUT IN'
81000 3'/10X, '(EX. WING - F:1=NAME, IN)')
82000^901 FORMAT(11)
83000^902 FORMAT(1H1,30X,'WING WEIGHT'/)
84000^903 FORMAT(1H1,25X,'HØRIZØNTAL TAIL WEIGHT'/)
85000^904 FORMAT(1H1,26X,'VERTICAL TAIL WEIGHT'/)
86000^905 FORMAT(1H0,5X,'ASPECT RATIO = 'F10.1,10X,'EXPOSED AREA = 'F1
0.0,
87000 A ' FT2')
88000^906 FORMAT(1H ,5X,'AREA, GRØSS = 'F10.0,' FT2'5X,'GRØSS WEIGHT
=
89000 B F10.0, ' LB')

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AEROSURF LISTING (Continued)

```

90000^907  F0RMAT(1H ,5X, 'TAPER RATIO'  = 'F7.4,13X, 'LOAD FACTOR  = 'F7.
3)
91000^908  F0RMAT(1H ,5X, 'ROOT T/C      = 'F7.4,13X, 'PRESSURE    = 'F7.
3,5X,
92000      C  'PSF')
93000^909  F0RMAT(1H ,5X, 'TIP T/C        = 'F7.4,13X, 'BODY SPAN    = 'F10
.1,
94000      D  'FT')
95000^910  F0RMAT(1H ,5X, 'SPAN'10X, '= 'F10.1, 'FT'5X, 'SWEEP ANGLE  = '
F7.4,
96000      E  5X, 'DEG')
97000^911  F0RMAT(1H ,5X, 'SURFACE LOAD  = 'F10.1,3X, 'LB'5X, 'MATERIAL'
98000      16X, '= 3A4)
99000^912  F0RMAT(1H ,5X, 'ROOT R.M.'5X, '= 'F10.0, 'FT-LB'5X
100000     2  'TEMPERATURE  = 'F7.0,3X, 'DEG.F'//)
101000^913 F0RMAT(1H ,8X, 'ELEMENT' 20X, 'EXP0SED'13X, 'CARRY-THRU'//7X
102000     A  'BENDING'10X, 'SHELL'16X, F10.0,12X, F10.0)
103000^914 F0RMAT(1H , 9X, 'BENDING'14X, F10.0,12X, F10.0)
104000^915 F0RMAT(1H , 6X, 'SHEAR'10X, 'SHELL'16X, F10.0,12X, F10.0)
105000^916 F0RMAT(1H , 9X, 'SHEAR' 16X, F10.0,12X, F10.0)
106000^917 F0RMAT(1H , 6X, 'RIBS' 20X, F10.0,12X, F10.0)
107000^918 F0RMAT(1H , 6X, 'JOINTS'18X, F10.0,12X, F10.0)
108000^919 F0RMAT(1H , 6X, 'STD.GAGE'16X, F10.0,12X, F10.0)
109000^920 F0RMAT(1H , 6X, 'MODEL' 19X, F10.0,12X, F10.0)
110000^921 F0RMAT(1H , 8X, 'SUBTOTAL' 14X, F10.0,12X, F10.0/)
111000^922 F0RMAT(1H ,10X, 'WTN-CPT.'12X, F10.0,12X, F10.0/)
112000^923 F0RMAT(1H , 8X, 'SUBTOTAL' 14X, F10.0,12X, F10.0/)
113000^924 F0RMAT(1H ,12X, 'TOTAL TORQUE'30X, 16X, F11.0)
114000^925 F0RMAT (1H ,12X, 'LEADING EDGE',20X, F11.0)
115000^926 F0RMAT (1H ,12X, 'FLAPS',27X, F11.0)
116000^927 F0RMAT (1H ,12X, 'AILERONS',24X, F11.0)
117000^928 F0RMAT (1H ,12X, 'TRAILING EDGE',19X, F11.0/)
118000^929 F0RMAT (1H ,12X, 'TOTAL WING',22X, F11.0)
119000^930 F0RMAT (1H ,12X, 'ELEVON'16X, 'SHELL',24X, F11.0)
120000^931 F0RMAT (1H ,15X, 'DRIVE RIB',20X, F11.0)
121000^932 F0RMAT (1H ,15X, 'HINGE',24X, F11.0)
122000^933 F0RMAT (1H ,15X, 'ATTACH',23X, F11.0/)
123000^934 F0RMAT (1H ,12X, 'TOTAL HORIZ TAIL',16X, F11.0)
124000^935 F0RMAT(1H ,12X, 'RUDDER'16X, 'SHELL',24X, F11.0)
125000^936 F0RMAT(1H ,15X, 'DRIVE RIB',20X, F11.0)
126000^937 F0RMAT(1H ,15X, 'HINGE',24X, F11.0)
127000^938 F0RMAT(1H ,15X, 'ATTACH',23X, F11.0/)
128000^939 F0RMAT(1H ,12X, 'TOTAL VERTICAL TAIL',13X, F11.0)
129000^950 F0RMAT (1H ,9X, 'KICK RIB',13X, F10.0)
130000^960 F0RMAT (1H ,9X, 'BEND REL',13X, F10.0)
130500 965 F0RMAT (1H,12X, 'MAIN GEAR PR0V',18X, F11.0)
130700 970 F0RMAT (1H,12X, 'SURF CNT PR0V',18X, F11.0)
131000^9996 GF TO 10
132000^9997 STOP 2222
133000^9998 STOP 3333
134000^9999 STOP 0000
135000     END

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AEROSURF LISTING (Continued)

```

136000      SUBROUTINE WING(J)
137000      REAL LAMB,LH,M,K,NZ,LE,KEAS,LAMPB,MP,KP,KMPP,KMC,MPP
138000      COMMON AR,SG,LAMB,TQCR,TQCT,BCT,THETA,WG,NZ,DELP,LH
139000      1,PTBXC,PTBXC,CB,RH2,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
140000      1,EMODU,WSWPKR,WBREL,WC1,WC2,CMI,BLP1,BLP2,BCMI
141000      2,WLE,ULE,CSR,TMIN,G(22),LE,WFLAP,WAIL,WTE,WT
142000      COMMON/RWRW/FLP,FCP,KEAS,AILP,AICP,UWAIL,CLE
142500      1,FG,GLM,Q,SMGDR,GPRDV,STE,CSPRDV
142600      2,SFLPTE,UFLPTE,SFLPLE,UFLPLE,SSLAT,USLAT,SSB,USB
143000      CALL TRSQX(J)
144000      BSC=BCT/3
145000      CR=(2.*SG)/(B*(1.+LAMB))
145100      TR=CR*TQCR
145200      CT=CR*LAMB
145300      TT=CT*TQCT
145400      IF (LAMB.EQ.0.) TT=TQCT
145500      N=TT/TR
145600      TF=TR*(1.+(N-1.)*BCT/B)
146000      BE=3-BCT
147000      STRE=PTBXC*SEXP
147100      OUTPUT(108)STRE
148000      CF=CP*(1.-BSC*(1.-LAMB))
149000      CRCF=CR/CF
149100      IF (AICP.EQ.0.) GO TO 39
149205      SAIL1=AILP*BE*AICP*CF
149206      SAIL=SAIL1/2.*(2.-(1.-LAMB)*CRCF*(1.-BSC)*(2.*FLP+AILP))
149400      CMAIL=SAIL/(AILP*BE)
149410      AILHM=SAIL*144.*KEAS*12.*CMAIL*.5*.001
149412      CX=CMAIL/AICP
149414      BX=(CX-CT)*BE/(CF-CT)
149416      TX=TT+(TF-TT)*BX/BE
149420      HLTR=(2.*TX/3.)*12.
149430      WAS=UWAIL*SAIL
149440      WADR=(CMAIL*(AILHM/HLTR)**.75)*2.
149450      WAH=(.40*AILP*BE*AILHM**.2)*2.
149460      WAIL=WAS+WADR+WAH
149470      GO TO 41
149480      39 SAIL=AILP
149490      OUTPUT (108) SAIL
149500      WAIL=UWAIL*SAIL
149600      41 CONTINUE
150000      WFLPTE=SFLPTE*UFLPTE
150100      OUTPUT(108)SFLPTE
150500      WFLPLE=SFLPLE*UFLPLE
150600      SFLAP=SFLPTE+SFLPLE+SSLAT+SSB
150700      OUTPUT(108)SFLPLE
151000      USLAT=SSLAT*USLAT
151100      OUTPUT(108)SSLAT
151500      WSB=SSB*USB
151600      OUTPUT(108)SSB

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AEROSURF LISTING (Continued)

```

152000 WFLAP=WFLPTE+WFLPLE+WSLAT+WSB
152500 P1=.25*WAIL
153000 P2=1.1*WFLPTE**.8
153500 P3=.55*WFLPLE**.8
154000 P4=.80*WSLAT**.7
154500 P5=2.5*SSB
155000 CSPRCV=P1+P2+P3+P4+P5
156000 SLE=CLE*SEXP
156100 OUTPUT(108)SLE
157000 LE=WLE*ULE
157500 TK=(CB+(500./FA)*RHQ*144.)/(0.7+(500./61000)*.1*144.)
157600 OUTPUT(108)TK
158200 IF(ULE.EQ.0.) LE=3.38*(.001*WG*NZ/SG)**.3*SLE*TK
158500 GPRCV=.43*Q**.3*SMGDR+.077*(FG*GLM*.001)**.90
159000 IF(STE.LT.1.) STE=SEXP-STBE-SFLAP-SAIL-SLE
159100 OUTPUT(108)STE
160200 WTE=1.87*STE*(.001*WG*NZ/SG)**.2*TK
161000 IF(WG.EQ.0..OR.NZ.EQ.0.) WTE=1.87*STE*(.001*DELP)**.2*TK
162000 WWT=G(22)+LE+GPRCV+CSPRCV+WFLAP+WAIL+WTE
163000 RETURN
164000 END
165000 SUBROUTINE HTAIL(J)
166000 REAL LAMB,LH,M,K,NZ,LE,LAMP,MP,KP,KMPP,KMC,MPP
167000 COMMON AR,SG,LAMB,TCCR,TCT,BCT,THETA,WG,NZ,DELP,LH
168000 1,PTBXC,PTBXC,CB,RHQ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
169000 1,EMODU,WSWPKR,WRREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
170000 2,WLE,ULE,CSR,TMIN,G(22),LE,WES,WEDR,WEH,WEP,TAIL
171000 COMMON/RWRHT/ELSC,ELCC,UEL,UES,ELB
172000 CALL TRQBXX(J)
173000 CEST=COS(THETA/57.2958)
174000 BE=B-BCT
175000 SEL=ELSC*SG
176000 CME=SEL/(B*(1.-ELB))
177000 HLTE=12.*CME*(TCCR+TCT)/2.
178000 HLE=3*(1.-ELB)/CEST
179000 EHM=SEL*144.*UEL*12.*CME*.5*.001
180000 LE=WLE*ULE
181000 WES=UES*SEL
182000 WEDR=.46*CME*(EHM/HLTE)**.75
183000 WEH=.40*HLE*EHM**.2
184000 WEP=.25*(WES+WEDR+WEH)
185000 TAIL=G(22)+LE+WES+WEDR+WEH+WEP
186000 RETURN
187000 END
188000 SUBROUTINE VTAIL(J)
189000 REAL LAMB,LH,M,K,NZ,LE,LAMP,MP,KP
190000 COMMON AR,SG,LAMB,TCCR,TCT,BCT,THETA,WG,NZ,DELP,LH
191000 1,PTBXC,PTBXC,CB,RHQ,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
192000 1,EMODU,WSWPKR,WRREL,WC1,WC2,CM1,BLP1,BLP2,BCM1
193000 2,WLE,ULE,CSR,TMIN,G(22),LE,WPS,WRDR,WRH,WRP,TAIL
194000 COMMON/RWRVT/RDC,RUDUL,URS

```

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TABLE 3.1-5  
AEROSURF LISTING (Continued)

```

195000 CALL TROBOX(J)
196000 COST=COS(THETA/57.2958)
197000 CR=(2.*SG)/(B*(1.+LAMB))
198000 CT=CR*LAMB
199000 TR=CR*TCR
200000 TT=CT*TCCT
201000 BE=B-BCT
202000 CMR=RDC*(CR+CT)/2.
203000 SRUD=RDC*SG
204000 RHM=SRUD*144.*RUDIL*12.*CMR*.5*.001
205000 HLTR=12.*(TR+TT)/2.
206000 HLLR=BE/COST
207000 WRS=WRS*SRUD
208000 WRDR=.46*CMR*(RHM/HLTR)**.75
209000 WRH=.40*HLLR*RHM**.2
210000 WRP=.25*(WRS+WRDR+WRH)
211000 LE=HLE*WLE
212000 TAIL=G(22)+WRS+WRDR+WRH+WRP+LE
213000 RETURN
214000 END
215000 SUBROUTINE TROBOX(J)
216000 REAL LAMB,LH,M,K,NZ,LAMBP,MP,KP,KMPP,KMC,MPP
217000 COMMON AR,SG,LAMB,TCR,TCCT,BCT,THETA,WG,NZ,DELP,LH
218000 1,PTBXC,PTBXE,CB,RHC,FA,CS,TAU,TEMP,UWW,B,SEXP,SL,RBM
219000 1,EMDU,WSWPKR,WBREL,WCI,WC2,CMI,BLP1,BLP2,BCMI
220000 2,WLE,HLE,CSR,TMIN,G(22)
221000 COST=COS(THETA/57.2958)
222000 B=(AR*SG)**.5
223000 CR=(2.*SG)/(B*(1.+LAMB))
224000 CT=CR*LAMB
225000 CF=CR*(1.-(1.-LAMB)*BCT/B)
226000 TR=TCR*12.*CR
227000 TT=TCCT*12.*CT
228000 IF(LAMB.EQ.0.) TT=TCCT
229000 M=TT/TR
230000 TF=TR*(1.+(M-1.)*BCT/B)
231000 MP=TT/TF
232000 RBSPC=TF*(.8+0.2*MP)
233000 IF(RBSPC.LT.12.) RBSPC=12.
234000 IF(MP.GT..99) MP=.99
235000 LAMBP=LAMB/(1.-(1.-LAMB)*BCT/B)
236000 KP=3.*LAMBP/(1.+LAMBP)*((1.-3.*MP)*(1.-MP)-2.*MP**2*ALOG(MP
))
237000 KP=KP/(1.-MP)**3
238000 KP=KP+(1.-LAMBP)/(1.+LAMBP)*((2.-7.*MP+11.*MP**2)
&*(1.-MP)+6.*MP**3*ALOG(MP))/3./(1.-MP)**4
240000 SCT=BCT*(CR+CF)/2.
241000 SEXP=SG-SCT
242000 OUTPUT(108)SEXP
243000 STBC=PTBXC*SCT
243100 OUTPUT(108)STBC
244000 STBE=PTBXE*SEXP
245000 WW=UWW*SG
246000 BE=B-BCT

```

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TABLE 3.1-5  
AEROSURF LISTING (Continued)

```

247000 TANT=SIN(THETA/57.2958)/COST
248000 TANLE=TANT+2*(1-LAMB)/(AR*(1+LAMB))
249000 TANTE=TANLE-4*(1.-LAMB)/(AR*(1+LAMB))
251100 ANGLE=57.2958*ATAN(TANLE)
251200 ETAWNG=(.04+AR*(.0049+.000045*ANGLE))*LAMB
253100 ETAWNG=ETAWNG-.05*(LAMB-.4)**2
255100 ETAWNG=ETAWNG+.41*(1+.00033*ANGLE)-(60.-ANGLE)/3000
257000 F=3.395-5.*ETAWNG
258000 GEE=AR*TANTE*(-.01484)
259000 H=(AR-4.)*(1.+3.5*TANTE)*0.003
260000 IF (AR.LT.4.) H=0
261000 CBARCL=F+GEE+H
262000 ETAF=BCT/B
263000 FF=F*(1-ETAF**2)**.5+(20.*ETAWNG-8.488)*ETAF**2*(1-ETAF**2)*
*.5
264000 GEEF=GEE*(1.-6.666*ETAF+7.316*ETAF**2)*(1-ETAF**2)**.5
265000 HF=H*(1.-14.5*ETAF**2+21.*ETAF**4)*(1.-ETAF**2)**.5
266000 CBARF=FF+GEEF+HF
267000 SLRATI=(CBARCL+CBARF)*ETAF/2
272000 ETAEXP=(ETAWNG-SLRATI*ETAF*.5-(1.-SLRATI)*ETAF)/(1.-SLRATI)
273000 ETAEXP=ETAEXP*B/BE
274000 ETAUNF=(2.*LAMP+1.)/(3.*(LAMP+1))
275000 RLCP=ETAEXP/ETAUNF
275200 SLTCT=((WG-.5*WW)*NZ+LH)
275500 SL1=SLTCT*(1.-SLRATI)
277000 SL2=DELP*SEXP
278000 SL=SL1
279000 IF (SL2.GT.SL1) SL=SL2
280000 RBM=RLCP*(SL/6.)*BE/(2.*COST)*(2.*LAMP+1.)/(LAMP+1.)
281000 IF (J.EQ.3) RBM=4*RBM
282000 TCB=CB*RBSPC/20
282510 PF=RBM/(TF*CF*PTRXE*.8)
283000 TCGVE=TCB/(RHC*144.)+PF/FA
284000 RRNN=2*PF**2*RBSPC/(EMZDU*TCGVE*TF*.8)
285000 TRIBF=TCB/(RHC*144.)+RRNN/FA
286000 TRSTF=67.5*RBM*12/(3.1416**2*EMZDU*PTRXE*CF*12*RBSPC)
287000 IF (TRSTF.GT.TRIBF) TRIBF=TRSTF
288000 TRIBT=TCB/(RHC*144.)
289000 WRIBF=RHC*TRIBF*TF*CF*PTRXE*12
291000 WRIBT=RHC*TRIBT*TT*CT*PTRXE*12
292100 USWPKB=.053*(ABS(SL*.001*SIN(THETA/57.2958))*BE/(COST*TF/12.))
)*.92
293000 G(1)=2.*CR*STBE
294000 G(2)=2.*CR*STBC
295000 G(3)=RHC*KP*BE*RBM*(1.+LAMP)/(FA*.8*TF*(2.*LAMP+1.))*144.
296000 G(4)=RHC*RRNN*2.*COST*BCT*144./(FA*.8*TF)
297100 TC=TR*(1-(1.-*)*3LPI*2/BE)

```

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TABLE 3.1-5  
AEROSURF LISTING (Continued)

```

298000 MPP=TC/TF
299000 KMPP=2*((1./(1.-MPP))+MPP*ALOG(MPP)/(1.-MPP)**2.)
300100 KMC=ALOG(MPP)/(MPP-1.)
300500 BL1=(BLP1-BCT/2)/COST
301000 WREL1=RH0*WC1*NZ*BL1**2*144.*KMPP/(FA*.8*TF)
302000 WREL1=WREL1+RH0*WC1*NZ*BL1*144.*COST*BCT/(FA*.8*TF)
303000 WREL1=WREL1+RH0*WC1*NZ*BL1*12./TAU
304100 TC=TR*(1-(1-M)*BLP2*2/BE)
304500 MPP=TC/TF
305000 KMPP=2.*(1./(1.-MPP)+MPP*ALOG(MPP)/(1.-MPP)**2)
305500 BL2=(BLP2-BCT/2)/COST
306000 WREL2=RH0*WC2*NZ*BL2**2*144.*KMPP/(FA*.8*TF)
308000 WREL2=WREL2+RH0*WC2*NZ*BL2*144.*COST*BCT/(FA*.8*TF)
309000 WREL2=WREL2+RH0*WC2*NZ*BL2*12./TAU
309500 WCM=4.*RH0*CM1*BCM1*144*KMC/(FA*.8*TF)
310000 WBREL=(-WREL1-WREL2+WCM)
311000 G(5)=12.*RH0*BE/COST*(2.*CS*(.8*TF*(1.+MP)/2.))**2
312000 &+TMIN*(.8*TF*(1.+MP))
313000 G(6)=2.*CB*.8*TF*BCT/12.
314000 G(7)=2.*RH0*RBH*12./TAU
315000 IF (J.LE.2) GO TO 150
316000 G(7)=G(7)*.5
317000 *150 G(8)=(WRIBF+WRIBT)/(2*RBSPC*COST)*BE*12
318000 G(9)=WRIBF/(RBSPC)*BCT*12
320000 G(10)=(G(1)+G(3)+G(5)+G(7)+G(8))*0.1
321000 G(11)=(G(2)+G(4)+G(6)+G(9))*0.1
322000 G(12)=.14*STBE
323000 G(13)=.14*STBC
324000 G(14)=.10*G(3)+.20*(G(7)+G(8))
325000 G(15)=.10*G(4)+.20*G(9)
326000 G(16)=G(1)+G(3)+G(5)+G(7)+G(8)+G(10)+G(12)+G(14)+WBREL+WSWP K
R
327000 G(17)=G(2)+G(4)+G(6)+G(9)+G(11)+G(13)+G(15)
328000 G(18)=.25*G(16)
329000 G(19)=.25*G(17)
330000 G(20)=G(16)+G(18)
331000 G(21)=G(17)+G(19)
332000 G(22)=G(20)+G(21)
333000 RETURN
334000 END

```





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3.2 Develop Body Basic Structure Model - The body is the largest individual weight group in the Orbiter, contributing between 20 and 30 percent of the inert weight. It is also the group requiring the greatest development. Although constructed with conventional materials and techniques, the cargo door, running the full length of the center fuselage, precludes a normal monocoque approach and increases the seriousness of torsion.

3.2.1 External Loads - The first subtask was to set up a viable loads model capable of predicting the critical cases. This model duplicates, as accurately as possible, the design loads for the Orbiter fuselage. The primary constraint in setting up the model was to minimize the input parameters. To accomplish this, three basic assumptions were made:

1. statically determinant reaction between the Orbiter and the tank.
2. single-condition critical loading with the exception of torsion.
3. torsion decreases from the maximum, at the aft reaction point, to zero at the forward reaction point.

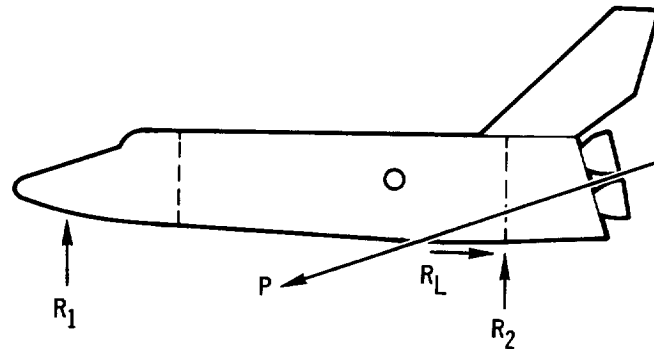
The following work develops the load model used in sizing the body basic structure.

Figure 3.2-1 depicts the basic load model set up to derive the interstage reaction between the Orbiter and the external tank. Vertical loads only are assumed taken at the forward attach point, and both vertical and longitudinal loads at the aft attach point. With these basic reactions known, "simple beam" shear and moment equations are written for the center fuselage.

Variables considered in this evaluation are:

1. Orbiter ascent thrust, including number of engines, thrust level, factor of safety, and thrust vector angle.
2. basic Orbiter geometry, including fuselage lengths and width, along with the location of the interstage reactions.
3. an estimated Orbiter liftoff weight (OLOW) and its cg location with the vertical and axial load factors corresponding to the design condition.

Figure 3.2-2 illustrates a typical design load envelope for an Orbiter as compared to the approximated envelope as defined by the load model. As noted in the design envelope, the post-SRM burnout condition is the designing factor for a large portion of the fuselage. This is the condition approximated by the load model, and the resulting moments are within  $\pm 5$  percent of the design envelope for the fuselage center section.



THE FOLLOWING EQUATIONS ARE SIMPLE STATIC SUMMATION OF FORCES AND GIVE THE RESULTING INTERSTAGE REACTIONS.

$$\begin{aligned}\Sigma \text{ MOMENT } \odot R_1 &= FS * OLOW * N_X * HO + OLOW * N_Z * (LI - LO) * FS \\ &\quad - FS * P \cos AOI * HV + FS * P \sin AOI * (LI + LV)\end{aligned}$$

$$R_2 = \frac{\Sigma \text{ MOMENTS } \odot R_1}{LI}$$

$$\begin{aligned}\Sigma \text{ MOMENT } \odot R_2 &= FS * P \cos AOI * HV - P \sin AOI * LV * FS \\ &\quad - OLOW * N_X * HO * FS + OLOW * N_Z * LO * FS\end{aligned}$$

$$R_1 = \frac{\Sigma \text{ MOMENT } \odot R_2}{LI}$$

$$R_L = P * FS * \cos AOI - OLOW * N_X * FS$$

FIGURE 3.2-1 LOADS MODEL

With a large nonstructural cargo door, torsional bending becomes a factor in estimating the basic fuselage structure. Assuming the maximum torsional load is defined by the max  $\beta_q$  condition (ascent side wind), an approximation can be made by taking the vertical tail design load as a moment about the fuselage shear center. This moment is then reacted by differential bending of the fuselage side panels as depicted in Figure 3.2-3. It is assumed that the torsional moment degrades as a straight line function from the aft to the forward interstage.

The torsion load is induced by the max  $\beta_q$  condition and is not concurrent with the post-SRM burnout condition defining the maximum fuselage bending loads. Consequently, the side panel  $\bar{t}$  resulting from this condition must be checked against the bending-designed side panels and delta increases added, if applicable.

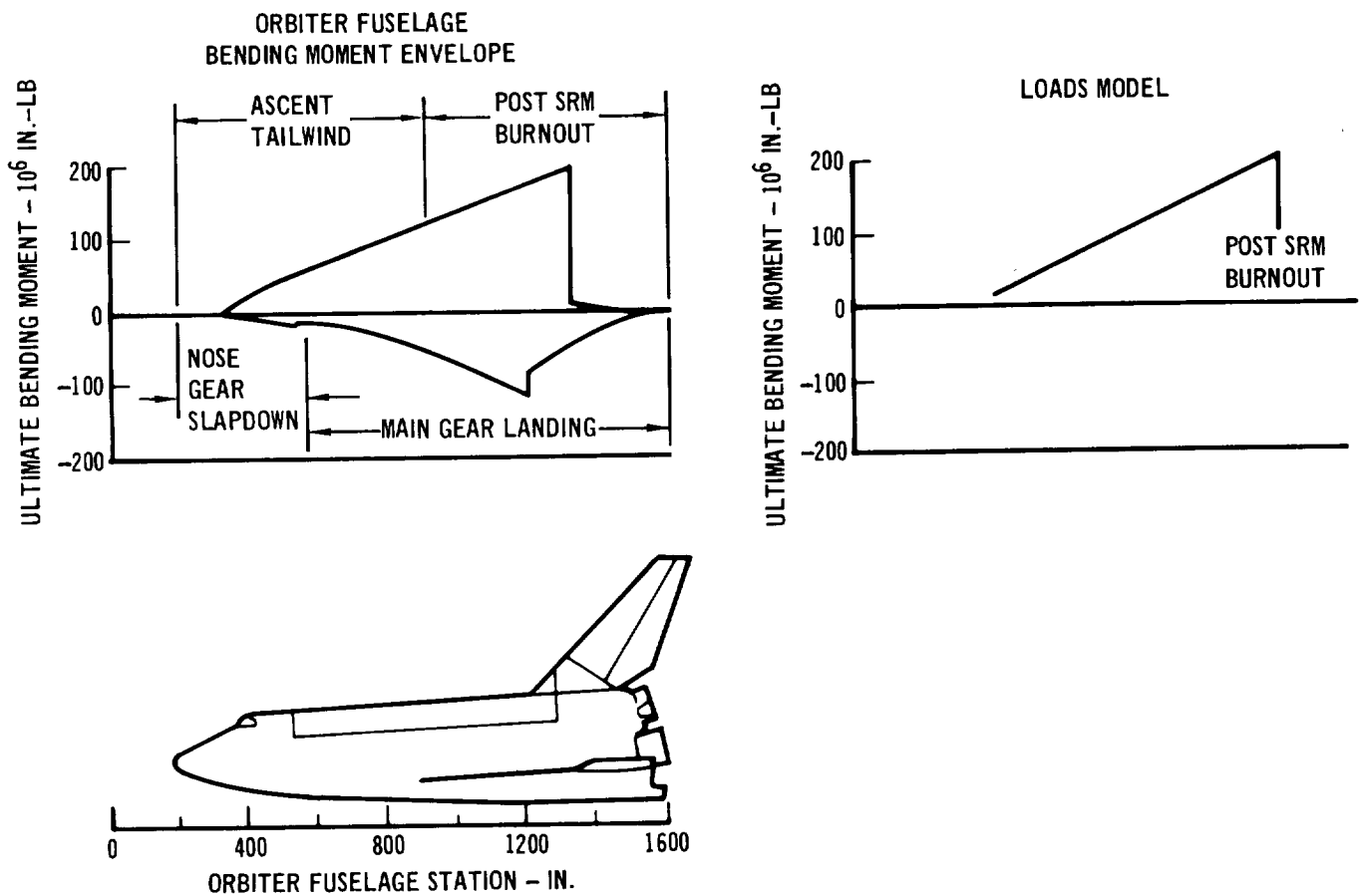


FIGURE 3.2-2 TYPICAL DESIGN LOAD ENVELOPE

The simple beam shear and moment equations are easily developed from the preceding assumptions and resulting interstage reactions.

Shear

$$V @ R_1 \text{ to } (LI-LO) = R_1$$

$$V @ (LI-LO) \text{ to } R_2 = R_1 - OLOW * N_z * FS$$

Moment

$$M @ x \text{ (x is the incremental location from } R_1 \text{ to } LI-LO) = R_1 * x$$

$$M @ y \text{ (y is the incremental location from the point } (LI-LO) \text{ to } R_2), \\ \text{assuming y is the aft interstage location (y = } L\emptyset) \\ = R_1 * (LI-LO) + OLOW * N_x * HO * FS + (R_1 - OLOW * N_z * FS)y$$

$$\text{Torque @ z (z is the incremental point from } R_2 \text{ to } R_1) = (T - \frac{T}{LI})z$$

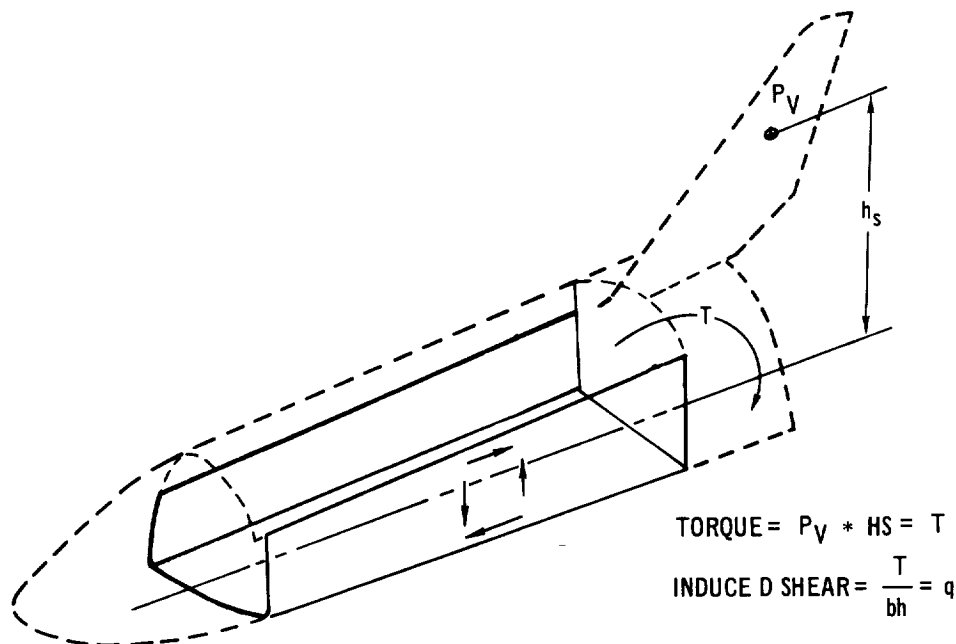


FIGURE 3.2-3 TORSION MODEL

A loads test case was run, based on the relationships developed on the previous pages. The primary critical condition for the fuselage center section is at post booster (SRM) burnout. This condition couples maximum Orbiter thrust with the minimum axial load factor, thus maximizing the interstage reactions and the induced Orbiter load. The design loads are defined by the Space Program Information Note No. SLE-LOADS-1 (Reference K), dated 7 June 1972, and documenting the MDAC loads from the proposal activity. The resulting interstage reactions develop a calculated forward interstage load of 199,200 lb, or 2-1/2 percent over the reference design load, and an aft vertical interstage load of 447,000 lb, or 3 percent over the reference design load. The aft interstage drag load results were not nearly as satisfactory with a calculated load of 1,654,000 lb, or 20 percent, under the reference design load. As this drag load is not directly involved in the determination of center section internal loads, no attempt has been made to improve the correlation. The following is the detail derivation of the interstage reactions.

Loads Test Case  
Post SRM Burnout

$\Sigma$  Moment @  $R_1$

$OLW \cdot NX \cdot FS \cdot HO + OLOW \cdot NZ + FS + (LI-LO)$

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$$\begin{aligned} & - FS * P * \cos AOI * HV + FS * P * \sin AOI * (LI+LV) \\ OLOW &= 204,000 \\ NX &= 0.808 \\ FS &= 1.4 \\ HO &= 129 \\ NZ &= 0.239 \\ LI &= 997 \\ LO &= 324 \\ P &= 470,000 * 3 = 1,410,000 \\ HV &= 140 \\ LV &= 100 \\ AOI &= 13 \text{ deg} \end{aligned}$$

Substituting and solving

$$= 4.456 * 10^8 \text{ in-lb}$$

$$R_2 = \frac{4.456}{997} * 10^8 = 447,000 \text{ lb vs. } 434,800 \text{ lb}$$

$\Sigma$  Moment @  $R_2$

$$\begin{aligned} & FS * P \cos AOI * HV - P \sin AOI * LV * FS \\ & - OLOW * NX * HO * FS + OLOW * NZ + LO * FS \end{aligned}$$

Substituting and solving

$$= 1.986 * 10^8 \text{ in-lb}$$

$$R_1 = \frac{1.986}{997} * 10^8 = 199,200 \text{ lb vs. } 205,950 \text{ lb}$$

3.2.2 Internal Loads - With the interstage reaction known, the next step is the determination of the internal loads. Two points are checked for analysis purposes, these being the forward and aft end of the cargo compartment, presuming these are the points of minimum and maximum moment respectively, with a constant gradient between the two points. Again, the reference for internal loads is the Program Information Note. The calculated moment at the forward end of the compartment is  $50 * 10^6$  in-lb, and is essentially identical to the design moment. The moment at the aft end of the compartment is  $207.1 * 10^6$  in-lb, and is 6 percent higher than the design moment. Similar results were determined for panel shear with the exception of the aft end of the compartment, but the overriding torsion condition is the critical case and produces viable results. The following

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is the detail determination of the simplified internal loads:

Bending Moment Test Case

$$\begin{aligned}M @ 570 &= R_1 * X \\X &= 570 - 318 = 252 \\M &= 199,200 * 252 = 50.2 * 10^6 \text{ in-lb vs } 50 * 10^6 \text{ in-lb} \\M @ 1320 &= R_1 (LI-LO) + OLOW * NX * HO * FS (R_1 - OLOW * NZ * FS)Y \\&= 199,200 (997 - 324) + 204,000 * 0.808 * 129 * 1.4 \\&\quad (199,200 - 204,000 * 0.239 * 1.4) 324 \\&= 207.1 * 10^6 \text{ in-lb} \\&\text{vs: } 195 * 10^6 \text{ in-lb}\end{aligned}$$

Shear Test Case

$$\begin{aligned}\text{Shear @ 570} &= R_1 \\&= 199,200 \text{ lb} \\&\text{vs: } 205,000 \text{ lb} \\ \text{Shear @ 1320} &= R_1 - OLOW * NZ * FS \\&= 199,200 - 204,000 * 0.238 * 1.4 \\&= 130,900 \text{ lb} \\&\text{vs: } 270,000 \text{ lb}\end{aligned}$$

Torsion Test Case

$$\begin{aligned}\text{Torque} &= PV * HS \\P_v &= 447 \text{ lb/ft}^2 \text{ ult} * 450 \text{ ft}^2 = 201,000 \text{ lb} \\h_s &= 0.4B + h_F - h_{sc} \\B &= 332 \\h_F &= 280 \\h_{sc} &= h_L/3 = 205/3 = 70 \\h_L &= 205 \\h_s &= 0.4 * 332 + 280 - 70 = 343 \\T &= 201,000 * 343 = 6.88 * 10^7 \text{ in-lb @ 1321 (aft end of cargo bay)} \\T &= 0 @ 570 \text{ (fwd end of cargo bay)}\end{aligned}$$

For analysis purposes, the body basic structure is broken down into three

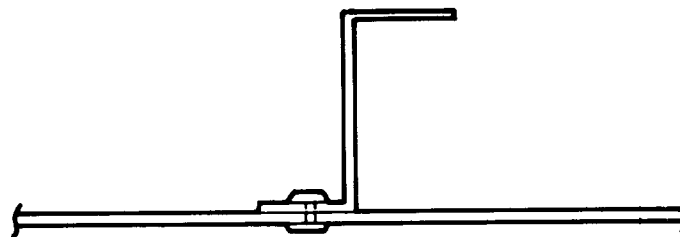
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distinct sections:

- (1) the forward section, which includes the crew cab and all structure ahead of the cargo compartment,
- (2) the center section, which is the full length of the cargo compartment, and
- (3) the aft section, including all thrust reaction material aft of the cargo compartment.

The following is a generalized nonoptimum factor included in the analytical models for the fuselage basic structure weight.



ASSUME 5% ATTACHMENT	5%
IDEALIZED STIFF SPACING, HEIGHT & THICKNESS	10%
BASIC SKIN GAGE MILL TOL $\pm .005$	8%
MISC STG'R CLIPS, SPLICES, ETC	5%
	<hr/> 28%

**3.2.3 Forward Section** - The forward section is separated into five components for the purpose of weight estimation. These components are the basic shell, pressurized cabin provision, windshield provision, nose landing gear provision, and a miscellaneous weight input.

The basic shell is treated as a pure function of surface area;  $WT = K * SFW$ , where  $K$  is the shell unit weight, and  $SFW$  is the wetted area of the forward section.

While not as attractive an approach as an analytical method, it will account for the known features of the baseline design. Applying the data from the NR-ATP Weight Report, Reference L, the shell unit weight becomes  $2.8 \text{ lb/ft}^2$ . It is assumed that the basic shell accounts for skin, stringer, frames, minor bulkhead, hatches, doors, and basic load reaction material.

The crew compartment is likewise treated by empirical relationship. The weight is derived by a modification of an existing equation in the MAC 747, Weight Estimation Handbook, Reference Q.  $WT = K(V_c)^{0.78}(1+P_c)^{0.35}$ , where  $V_c$  is the

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pressurized volume of the crew compartment, and  $P_c$  is the ultimate pressure differential. The multiplier K was 1.54 in the original equation, but curve fits to 3.08 against the NR-ATP baseline. It should be noted that the original multiplier was for relatively small cockpit volumes with relatively high leak rate, while the Shuttle has a large volume, very low leak rate requirements, and rather stringent fail-safe requirements. With this in mind, doubling the multiplier to the new curve fit seems reasonable, and the equation becomes  $WT = 3.08(V_c)^{0.78} (1+P_c)^{0.35}$  and is assumed to include the entire pressurized compartment with the exception of window provisions.

The weight estimation of windshield provisions is based on Timoshenko's flat plate analysis. Roark, Reference C, presents this relationship in simplified terms.

$$FTU = \frac{0.75 \Delta P b^2}{t^2 (1+1.61 \alpha^3)}$$

where

FTU is the ultimate material allowable,  
 $\Delta P$  is the maximum pressure differential,  
b is the maximum dimension of the plate,  
t is the thickness, and  
 $\alpha$  is the plate aspect ratio (width/height).

The windshield panels on the baseline orbiter are approximately square, simplifying the relationship;

$b^2$  is approximately the area of a panel, and  $\alpha$  is approximately equal to 1.

The equation thus becomes

$$FTU = \frac{0.75 \Delta P S_w}{t^2 * 2.61}$$

and

$$t = \left( \frac{0.75 \Delta P S_w}{2.61 FTU} \right)^{1/2}$$

The panel weight is then

$$WT = \rho * S_w \left( \frac{0.75 \Delta P S_w}{2.61 FTU} \right)^{1/2}$$

It is assumed that the window panels are fused silica with an FTU of 6800 lb/in<sup>2</sup> and a density ( $\rho$ ) of 0.08 lb/in<sup>3</sup>.

The windshield sill weights are based on a point design unit weight of 0.5 lb/in of sill. Again, assuming square panels for deriving the circumference, the total sill length becomes  $(S_w)^{1/2} * 4 * \text{Quantity}$ , and  $WT = 0.5 (S_w)^{1/2} * 4 * \text{Quantity}$ .



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3.2.4 Center Section - The center section estimation model shown below is based on the assumption of a longeron type design with all bending loads being carried by the longerons, and shear by the side panels. In addition, the side panels carry the distributed torsion load in differential bending. The allowables are derived by the shell program which models a single-faced corrugation as a weight estimation tool (Appendix A). This allows consideration of material properties dependent on alloy and temperature as well as on frame spacing. The analogy to the shell program is that the longeron supported by frames is similar to the beam column with semifixed end conditions, i.e., one side fixed and one side pinned. The center section model is shown in Figure 3.2-4.

Basic Shell - The following is the initial test case for section cuts on the MDC Phase C/D proposal Orbiter. The results indicate the current model would predict a section at the forward end of the cargo compartment approximately 15 percent lower than ideal detail design results, and approximately 8 percent lower at the aft end of the compartment.

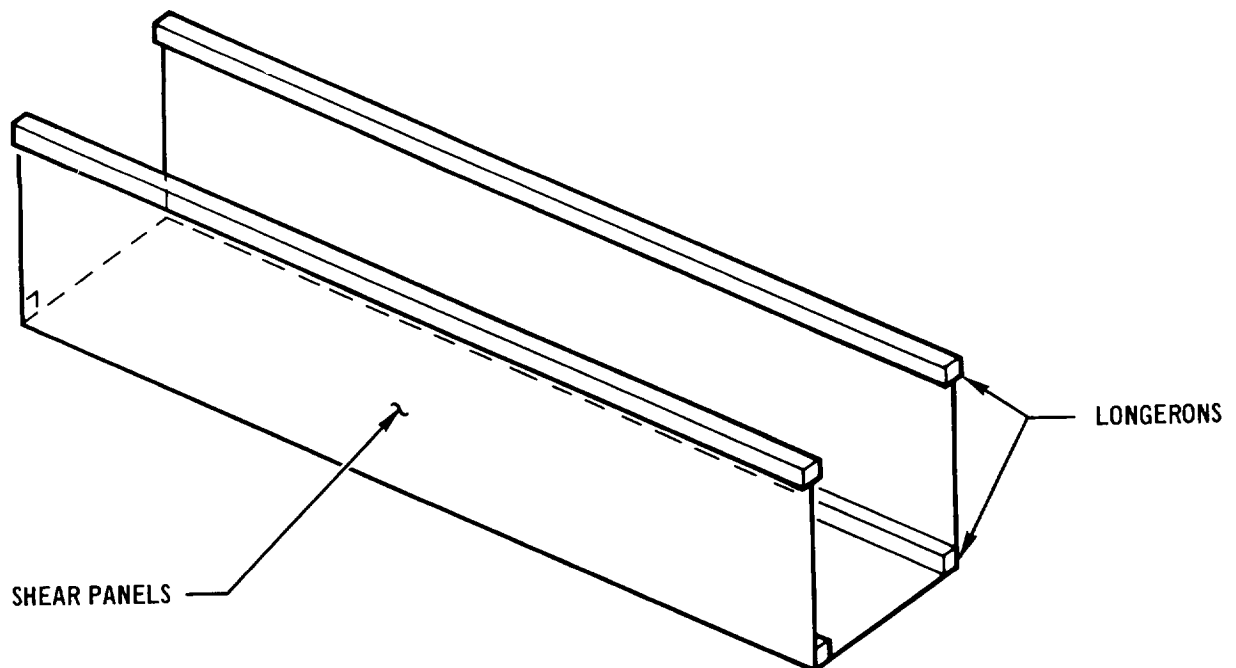


FIGURE 3.2-4 CENTER SECTION MODEL

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## Test Case - Section Cuts

FS 1321 - Aft end of Payload Bay

Material 2024 T86 Temp 70°F P - 1.4 lb/in<sup>2</sup> ult

Frame Spacing = 20 in

FA = 69,000 lb/in<sup>2</sup> False allowable from shell program

TAU = 22,300 lb/in<sup>2</sup> Shear allowable from-shell program

HL = 210 in Height between upper and lower longeron

B = 216 in Body width

$$P = \frac{M}{HL} = \frac{207.1 * 10^6}{210} = 0.985 * 10^6 \text{ lb}$$

$$A_{\text{Req'd}} = \frac{P}{FA} = \frac{985000}{69000} = 14.3 \text{ in}^2$$

$$\Sigma \text{ Area (upper \& lower longerons)} 2 * 14.3 = 28.6 \text{ in}^2$$

$\bar{t}$  min = 035 - input for shear panels

$$q = \frac{V}{HL} = \frac{130,900}{210} = 623 \text{ lb/in}$$

$$T = 6.88 * 10^7 \text{ in-lb}$$

$$q = \frac{T}{BHL} = \frac{68.8 * 10^6}{210 * 216} = 1520 \text{ lb/in}$$

$$\bar{t} = \frac{1520}{22,300} = .068$$

$$\begin{aligned} \text{x-sec} &= q * (B + 2HL) = 0.068 (210 * 2 + 216) \\ &= 43.3 \text{ in}^2 \end{aligned}$$

$$\text{Total Area} = 28.6 + 43.3 = 71.9 \text{ in}^2$$

Section at FS 570 - Fwd end of payload bay

Material Properties - Same

$$P = \frac{M}{H_L} = \frac{50.2 * 10^6}{150} = 313,000 \text{ lb}$$

$$A_{\text{req'd}} = \frac{P}{F_A} = \frac{313,000}{69,000} = 4.5 \text{ in}^2$$

$$\Sigma \text{ Area} = 9 \text{ in}^2 \text{ upper and lower longeron}$$

$\bar{t}$  min = .035- input -

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$$V = 199,200$$

$$q = \frac{199,200}{150 \times 2} = 665 \text{ lb/in}$$

$$\bar{t} = \frac{q}{\tau} = \frac{665}{22,300} = 0.030 \quad 0.035 \text{ min}$$

$$x\text{-sec} = (2 \times 150 + 216) 0.035 = 18.1 \text{ in}^2$$

$$\text{Total Area} = 27.1 \text{ in}^2$$

Frames - Intermediate or nonmajor load redistribution frames have long been a problem in the area of weight estimation. For circular sections, Shanley (Reference D), gives quite satisfactory results by solving a spring analogy to prevent general instability. An approximation of this method was tested, using the maximum dimension, fuselage height or width, as the effective diameter, and solving for the section modulus required to produce the required spring constant.

$$EI = C_f \frac{MD^2}{L}$$

$$I = \text{moment of inertia} = 2 \frac{A_c D_f^2}{4}$$

$D_f$  = frame depth

$C_f$  = experimental constant = 1/16,000

$M$  = maximum moment

$E$  = Youngs modulus

$L$  = frame spacing

$D$  = diameter

$A_c$  = area per cap

Substituting and solving for area

$$A_c = C_f \frac{MD^2}{L} \times \frac{2}{D_f^2}$$

Assuming a balanced frame with the web equal to one third the total cross sectional area

$$x\text{-sec} = 6 C_f \frac{MD^2}{LD_f^2}$$

Substituting values for the variable and solving for area

$$x\text{-sec} = 0.475 \text{ in}^2$$

This value is 20 percent lower than the theoretical point design which is redistribution of the differential pressure. Although this instability criteria

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is not the critical case, this analysis is maintained in the final program as a check against large bending moments.

Figure 3.2-5 shows a simplified frame model set up to duplicate the pressure critical design.

Assuming the sides are modeled by the criteria of one end fixed and one end pinned, the moment equation is

$$M = \frac{PB^2}{8}$$

Similarly, for the bottom, assuming both ends fixed, the moment equation is

$$M = \frac{Pb^2}{12}$$

where:  $M$  = derived bending moment,

$P$  = ultimate differential pressure,

$h_L$  = frame or longeron height per loads model,

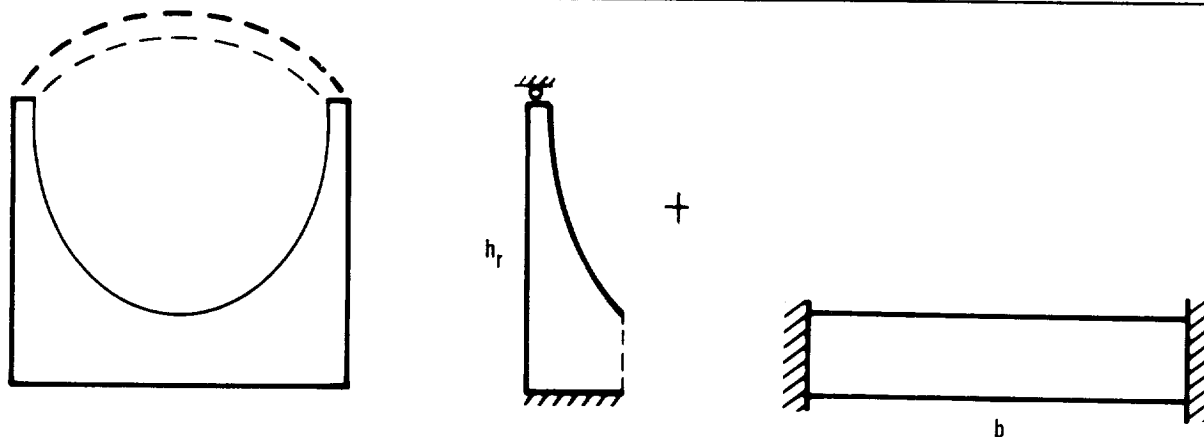
$B$  = fuselage width, and

$F_A$  = shell program resulting allowable

Solving for area the equations become:

$$\text{Side } A_c = \frac{Ph^2}{8D_f F_A}$$

$$\text{Bottom } A_c = \frac{Pb^2}{12D_f F_A}$$



BREAKING THE FRAME DOWN INTO SIMPLIFIED COMPONENTS

FIGURE 3.2-5 SIMPLIFIED FRAME MODEL

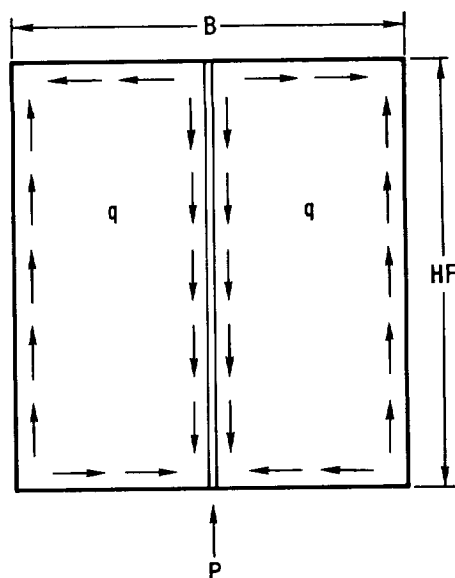
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Maintaining the relationship of a balanced frame with the web equal to one third the total section and sizing to an ultimate differential pressure of  $1.4 \text{ lb/in}^2$ , the cross sectional area becomes  $0.56 \text{ in}^2$  and is 3 percent lower than the theoretical point design. This simplified model will measure geometry and differential pressure, and when coupled with the resultant allowables from the shell program, considers material properties.

Special increments are required to complete the center section. These are (a) the bulkheads at the forward and aft end of the cargo bay, (b) payload reaction provisions, (c) wing carry-thru structure, and (d) wing shear tie provisions. In addition, secondary structures, consisting of the cargo doors and their associated mechanism, are included in this section.

The bulkheads at the forward and aft ends of the payload compartment are assumed to be sized for the critical load of interstage reactions. The estimation model is based on the principle of redistributing a concentrated external load into the basic structure as shown in Figure 3.2-6. The concentrated load is assumed to be reacted by a "shear beam" type bulkhead with the web sized to the derived shear flow and the caps sized on redistribution material. As with the basic shell, the shell program is utilized as the structural element model.



## WEB SHEAR FLOW

$$q = P/2HF$$

$$\text{WEB } \tau = q/\text{TAU}$$

$$W_T = \rho * \frac{P}{2HF} * \frac{1}{\text{TAU}} * \text{BHF} = \frac{P}{\text{TAU}} * \frac{P}{2} * B$$

$$\text{AUG CAP LOAD} \quad P/2$$

$$\text{AUG CAP AREA} \quad P/2FA$$

$$\text{TOTAL CAP LENGTH} \quad 4HF + 2B$$

$$W_T = \rho * \frac{P}{2FA} * (4HF + 2B)$$

FIGURE 3.2-6 TYPICAL BULKHEAD MODEL

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The payload reaction provisions are an input weight predicated on the number of reaction points. The weight increment is based on the following detail derivation shown in Figure 3.2-7.

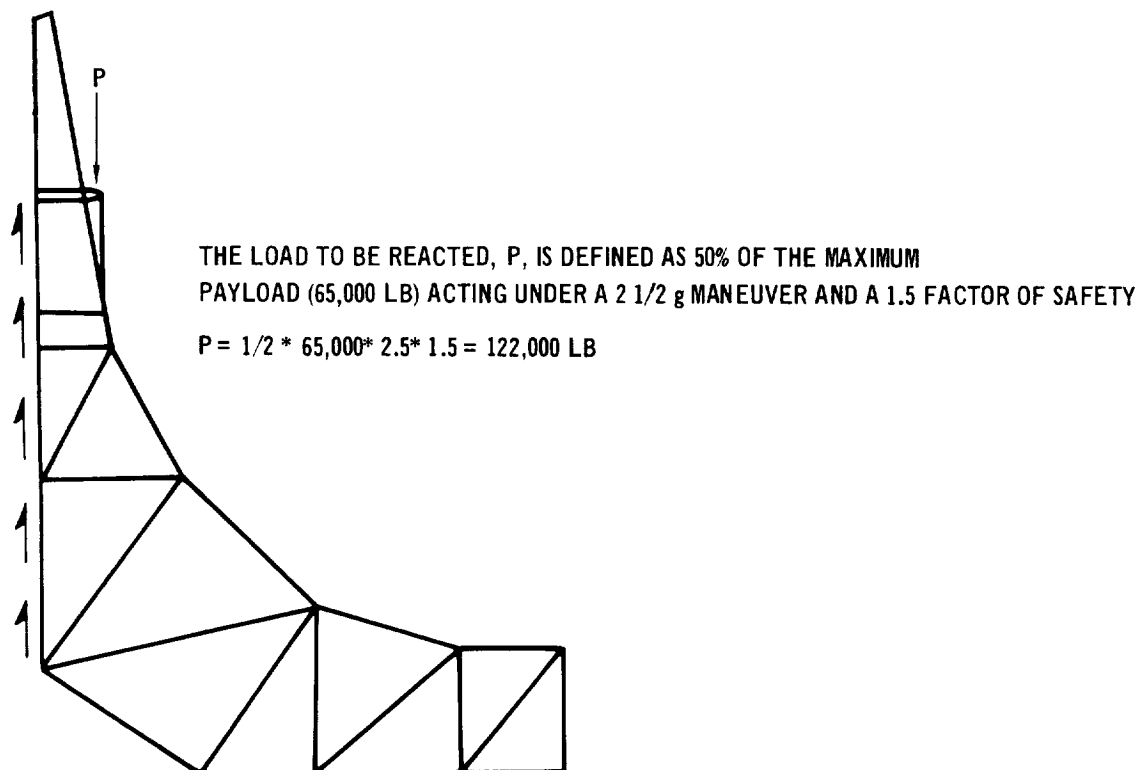


FIGURE 3.2-7 PAYLOAD REACTION

Sizing the frame caps to transfer the load into the sidewall gives the following weight:

$$\frac{P}{FAU} * 1/2 = \text{average cross-sectional area per cap}$$

$$\frac{122,000}{69,000} * 1/2 = 0.89 \text{ in}^2 \text{ per cap}$$

$$\text{Weight} = 0.89 \text{ in}^2 * 210 \text{ in} * 0.1 \text{ lb/in}^3 * 2 = 37 \text{ lb for both caps.}$$

Average shear flow becomes

$$\frac{122,000 \text{ lb}}{95 \text{ in}} = 1280 \text{ lb/in}$$

$$\text{and } \bar{t} = \frac{q}{\tau} = \frac{1280}{22,300} = 0.057 \text{ in}$$

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and the web weight becomes

$$210 * 8 * 0.57 * 0.1 = 10 \text{ lb}$$

The sidewall skin must be increased to accept this local shear input.

Assuming a 20 in frame spacing, and the load being applied on two bays, the weight increment becomes:

$$\frac{1280}{2} * \frac{2}{22,300} * 40 * 210 * 0.1 = 48 \text{ lb}$$

Summarizing,

caps 37 lb

web 10 lb

skin 48 lb

Total = 95 lb per reaction point

Assuming three reaction points per payload configuration to maintain fully determinant status, the total weight increment becomes  $3 * 95 \sim 300 \text{ lb}$ , and the vehicle penalty becomes  $300 * \text{number of payload positions}$ , assuming all axial loads are carried by the existing longeron structure.

The wing carry-thru structure is derived by the wing aerosurface routine and listed under body center section for consistency in reporting.

The wing shear tie provisions are derived by an empirical relationship defined in the MAC 747 Report, Reference Q.

$$WT = 0.8 (WgNz) \left( \frac{SPAN}{\cos \theta} \right) * 10^{-2}$$

where  $Wg * Nz$  is the ultimate total wing load, and  $\theta$  is the sweep angle at the 50 percent chord.

The center section secondary structure consists of the cargo door and its related mechanism. A comparison was made of the details composing the NR-ATP baseline and the MDC Phase C-D proposal cargo doors. The weights were adjusted for area and double doors versus single door with the following results:

	<u>NR</u>	<u>MDC</u>
Door Structure	4486	
Basic Shell	-	2800
Hinges	-	1360
Sealant	-	250
Electromechanical	<u>556</u>	<u>660</u>
Total	5042 lb	5070 lb

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It is readily seen from this comparison that, for a lightly loaded structure such as the cargo door, a unit weight approach is quite reasonable. Therefore, with the basic shell a function of area, the hinges, a function of bay length and quantity of doors, and holding the electromechanical system constant, the relationship becomes:

$$\begin{aligned}\text{Basic shell} &= 1.585 * (\text{SCD}) \\ \text{Hinges and sealant} &= 1.415 * (\text{LCB}) * (\text{Qty}) \\ \text{Mechanism} &= 660 \text{ lb}\end{aligned}$$

3.2.5 Aft Section - The aft skirt is separated into the following basic structural elements, plus a miscellaneous weight input to account for such things as equipment bays. These structural elements are: the sidewalls, longerons, frames, thrust structure, and the vertical tail provision.

The sidewalls include the skin and stringers and are sized as a unit weight times the surface area. The unit weight is the same as that derived for the center section and is predicated on direct shear, torsional shear, or the input minimum gage.

The longerons are sized as a continuation of the center-section longerons and taper in cross-sectional area to zero at the end of the fuselage.

The frames are sized identically with the center section frames, that being to react to the pressure differential with a check against general instability.

The thrust structure is weighed as three separate allowances. An engine adaptor fitting is included as a constant weight times the number of engines. The adaptor weight is based on a point design analysis. The final two allowances are direct thrust reaction material. The thrust posts are weighed as column members reacting to the direct engine thrust. The column length is predicated on the relative location of the composite thrust vector and a material allowable is derived, based on an assumed Euler column, giving aluminum an  $F_C \sim 40,000$  psi. In addition, a gimbal plane bulkhead is weighed, using methods identical to those for the interstage bulkhead but considering the thrust vector for the design load.

3.2.6 Symbols - The following symbols are listed in Fortran language as they were used in the derivation of equations and in the body weight program. Figure 3.2-8 depicts the location of the fuselage sections and some of the primary symbols.

For convenience, the material allowable symbols are listed separately for each section of the vehicle and for the element they represent. The numerical values



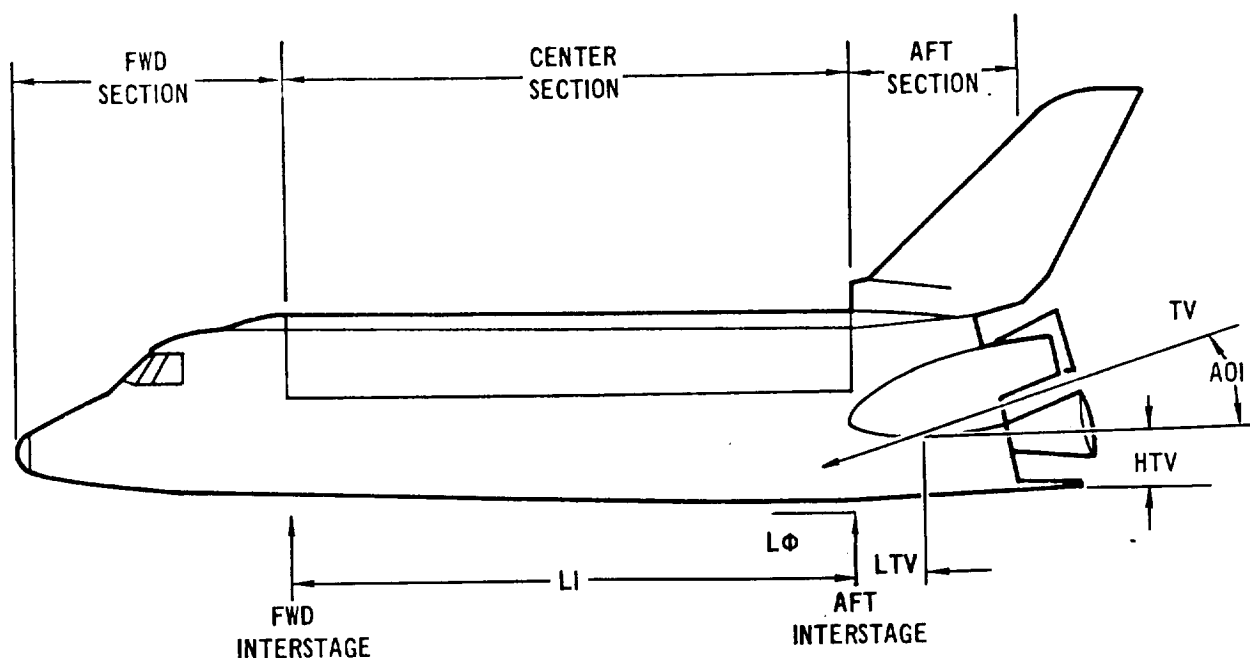


FIGURE 3.2-8 LOCATION OF FUSELAGE SECTIONS

of the allowables are taken from the "Shell" program in the Appendix, and allow variation in type of material or temperature environment for each element.

CONFIGURATION DEPENDENT VARIABLES

<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
AØI	deg	Angle of intersection of the composite thrust vector and the center line of the propellant tank
B	in	Average fuselage center section width
DELP	lb/in <sup>2</sup>	Ultimate pressure differential in the center section (vent lag, external, etc.)
DFAC	ND	Dynamic factor on ascent engines
FNG	lb	Ultimate design load on the nose gear strut
FS	ND	Factor of safety at the critical condition
HF	in	Average height of the center fuselage
HØ	in	Height of the orbiter lift-off weight CG above the aft interstage attach point

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<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
HL	in	Average height of the cargo door sill above the fuselage bottom
HTV	in	Height of the intersection between the composite thrust vector and the engine gimbal plane above the aft interstage attach point
K1	lb/ft <sup>2</sup>	Unit weight of the forward fuselage shell
K2	ND	Number of payload "tie down" locations
K3	ND	Cargo door indicator; 1 if hinged on one side; 2 if hinged on both sides
K4	lb	Center section miscellaneous weights input
K5	ND	Number of ascent engines
K6	lb	Aft section miscellaneous weight input
K7	lb	Forward fuselage miscellaneous weight input
LFS	in	Average center section frame spacing
LI	in	Length between the forward and aft interstage attach points
LØ	in	Length of the orbiter lift-off weight CG forward of the aft interstage attach point
LNG	in	Extended length of the nose gear strut
LTV	in	Length of the intersection between the composite thrust vector and the engines gimbal plane aft of the aft interstage attach point
ØLØWT	lb	Orbiter lift-off weight - estimated
ØLAWT	lb	Orbiter design aircraft flight weight - estimated
N <sub>X</sub>	ND	Axial limit load factor on the orbiter at the critical condition
N <sub>Z</sub>	ND	Vertical limit load factor on the orbiter at the critical condition
PC	lb/in <sup>2</sup>	Limit operating pressure in crew compartment
PV	lb	Ultimate design load on the vertical tail
Q	lb/ft <sup>2</sup>	Maximum dynamic pressure on the orbiter

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<u>SYMBOL</u>	<u>UNIT</u>	<u>DESCRIPTION</u>
SAW	ft <sup>2</sup>	Wetted area of the aft fuselage
SCD	ft <sup>2</sup>	Area of the cargo door
SFW	ft <sup>2</sup>	Wetted area of the forward fuselage
SND	ft <sup>2</sup>	Area of the nose landing gear doors
SW	ft <sup>2</sup>	Total windshield area
THETA	deg	Wing sweep angle at 50% chord
TMIN	in	Minimum thickness ( $\bar{t}$ ) of the center section side panels
TV	lb	Ascent engines vacuum thrust per engine
VC	ft <sup>3</sup>	Volume of the pressurized crew compartment
VTB	in	Vertical tail span
WB	ft	Wing span
WNZ	ND	Ultimate aircraft flight mode vertical load factor
X	in	Length between the forward interstage attach point and the forward cargo compartment bulkhead when the attach point is fwd of the bulkhead

MATERIAL DEPENDENT VARIABLES

Longeron

FAL	lb/in <sup>2</sup>	Material false allowable from shell program density
RHOL	lb/in <sup>3</sup>	

Shell

TAUS	lb/in <sup>2</sup>	Material shear allowable from shell program density
RHOS	lb/in <sup>3</sup>	

Frames

FAF	lb/in <sup>2</sup>	Material false allowable from shell program density
RHOF	lb/in <sup>3</sup>	
EF	lb/in <sup>2</sup>	Modulus of elasticity

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## Bulkhead

FAB	$\text{lb/in}^2$	Material false allowable from shell program
TAUB	$\text{lb/in}^2$	Material shear allowable from shell program
RHOB	$\text{lb/in}^3$	density

## Thrust Post

ET	$\text{lb/in}^2$	Modulus of elasticity
RHOTP	$\text{lb/in}^3$	density

## Gimbal Plane Bulkhead

FAPB	$\text{lb/in}^2$	Material false allowable from shell program
TAUPB	$\text{lb/in}^2$	Material shear allowable from shell program
RHOPB	$\text{lb/in}^3$	density

3.2.7 Test Case - Table 3.2-1 is a listing of a typical input file for the body structure weight program. Lines one through ten represent all of the required inputs, and the case listed is the NR baseline Orbiter with the results and typical printout shown in Table 3.2-2. Lines 12 through 14 represent changes to this basic file necessary to run a different configuration. In this case, the vehicle represented is the MDC Orbiter. The output for this case is listed in Table 3.2-3. The results of these two test cases compare extremely well with the adjusted body group weights of the reference vehicle. The NR run indicates a body weight of 31,693 lb versus an adjusted reported weight of 31,547 lb. The weight was adjusted by deleting the wing carry-thru weight and the radiator hinges for a direct comparison. The MDAC run produces a body weight of 32,962 lb and compares to a calculated weight of 32,500 lb.

3.2.8 Program Listing - Table 3.2-4 is the listing of the body structure weight estimation program. This program is completely self-contained and can be used for comparative studies. Minor differences exist between this basic program and the body model in the ESPER program. Many of the input variables are derived in ESPER and need not be an input or are already input for a different model requiring the same data. An example would be vertical tail data used in the body for calculating torsion. The loads and geometry would be inherent in the vertical tail model.

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TABLE 3.2-1  
INPUT FILE

```

1.000  ACI=15.,HTV=100.,LTV=155.,PC=110.,LG=235.,LI=747.
2.000  NX=.3,NZ=.3,TV=470000.,FS=1.4,PLGWT=237655.,VTB=300.
3.000  PV=202500.,HF=253.,HL=145.,B=205.,Y=0.,K1=2.3
4.000  SFW=1278.,VC=2912.,PC=14.7,Q=650.,SND=30.6,FNG=119000.
5.000  LNG=77.,FAL=69000.,TAUS=22300.,TMIN=.035,RHQL=.1,RHQS=.1
6.000  EF=10300000.,LFS=20.,DELP=1.4,RHGF=.1,K2=4.,K3=2.,K4=0.
7.000  SCD=1764.,SAW=309.,DFAC=1.3,ET=10300000.,RHQTP=.1
8.000  RHQPB=.1,K5=3.,K6=120.,PLAWT=215000.,WNZ=3.75,WP=34.,THETA=10.
9.000  FAF=69000.,FAB=69000.,RHQB=.1,K7=0.
10.000 TAUB=22300.,FAPB=69000.,TAUPB=22300.,SW=41.6,Y7=0.
11.000 *
12.000  ACI=13.,HTV=133.,LTV=105.,HF=120.,LG=215.,LI=1020.
13.000  VTB=330.,HF=250.,HL=170.,B=230.,SFW=1162.,VC=2614.
14.000  SCD=1500.,SAW=1491.,Y=275.,K3=1.
15.000 *
--EOF HIT AFTER 15.

```

\*

TABLE 3.2-2  
NR BODY GROUP

BODY GROUP	31693.		
	FWD	CTR	AFT
BASIC STRUCTURE			
SIDEWALLS	3573.	3461.	1417.
LONGERONS		1065.	402.
FRAMES		1436.	1028.
BULKHEADS		1176.	
CREW CPT. PRV.	5124.		
WINDSHIELD PRV.	1637.		
NOSE WHL. WELL PRV.	225.		
PAYLOAD REACTION		1200.	
WING CARRY THRU.		550.	
WING SHEAR PRV.			
THRUST STRUCTURE			3936.
TAIL PRV.			162.
SUB TOTAL	10614.	8888.	7001.
SECONDARY STRUCTURE			
CARGO DOOR SHELL		2796.	
CARGO DOOR MECH.		2274.	
MISC.	0.	0.	120.
TOTAL	10614.	13958.	7121.

TABLE 3.2-3  
MDAC BODY GROUP

BODY GROUP	FWD	CTR	AFT
BASIC STRUCTURE			32962.
SIDEWALLS	3254.	3555.	2337.
LONGERONS		2252.	629.
FRAMES		2169.	1402.
BULKHEADS		1096.	
CREW OPT. PROV.	4710.		
WINDSHIELD PROV.	1637.		
NOSE WHL. WELL PROV.	225.		
PAYLOAD REACTION		1200.	
WING CARRY THRU.			
WING SHEAR PROV.		550.	
THRUST STRUCTURE			3711.
TAIL PROV.			162.
SUB TOTAL	9875.	10822.	8302.
SECONDARY STRUCTURE			
CARGO DOOR SHELL		2377.	
CARGO DOOR MECH.		1465.	
MISC.	0.	0.	120.
TOTAL	9875.	14665.	8422.

TABLE 3.2-4  
PROGRAM LISTING

```

3.100 SFIXED
1.000 IMPLICIT REAL(A-Z)
2.000 NAMELIST
3.000 1 ACI,HTV,LTV,HG,LC,LI,NY,NZ,P,FS,CLOMT
4.000 2,VTB,PV,HF,HL,P,V
4.100 3,K1,SFW,VC,PC,Q,SNB,FNG,LNG
4.200 4,FAL,TMIN,RHCL,RHCS,TAUS
4.300 5,SE,LFS,DELP,FAR,RHOB,TAUR
4.400 6,RHOF,Y2,SW,K7,TV
4.500 7,K3,Y4,SCD,FAF
4.600 8,CAW,FAPB,TAUPB
4.700 9,DEAC,ET,RHCTP,RHOPB,K5
4.800 8,K6,PLAWT,WNZ,WB,THETA
5.000 CALL EOFSET(99999)
6.000 1 INPUT(1)
7.000 C COMMENT CALCULATIONS DUE TO INTERSTAGE REACTIONS
7.500 P=TV*K5

```

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TABLE 3.2-4  
PROGRAM LISTING (Continued)

```

2.000      SMAR1=(FS*QLQWT*NX*H0)+(QLQWT*NZ*(LI-L0)*FS)
5.000      1-(FS*P*COSS(A0I/57.2953)*HTV)+(FS*P*SIN(A0I/57.2953)*(LI+L
IV))
10.000     SMAR2=(FS*P*COSS(A0I/57.2953)*HTV)-(P*SIN(A0I/57.2953)*LTV
*FS)
11.000     1-(QLQWT*NX*H0*FS)+(QLQWT*NZ*L0*FS)
12.000     R2=SMAR1/LI
13.000     R1=SMAR2/LI
14.000     RL=P*FS*COSS(A0I/57.2953)-QLQWT*NX*FS
15.000 C    SHEAR CALCULATIONS
16.000     SR1TL=R1
17.000     SLTR2=R1-QLQWT*NZ*FS
18.000 C    MOMENT CALCULATIONS
19.000     MR1TL=R1*X
20.000     MLTR2=R1*(LI-L0)+QLQWT*NX*H0*FS
21.000     1+(R1-QLQWT*NZ*FS)*L0
22.000 C    TORQUE CALCULATIONS
23.000     TR2 TR1=PV*(.4*VIB+HF-(HL*HL/(2.*HL+B)))
24.000 C    FWD SECTION WEIGHT CALCULATIONS
25.000     G1=K1*SW
26.000     G2=3.03*VC** .73*(1.+2.*PC)** .35
26.010     FW=6800.
26.020     PH2W=.03
26.100     GW=2.*((.75*3.*PC*144.*SW)/(6.*FW*2.61))**.5*SW*RH2W*144.
26.200     GS=.5*(SW/6.)*.5*233.
26.300     G3=GW+GS
27.000     G4=.33*Q**.3*END
28.000     G5=.039*(FNG*.001*LNG)**.9
28.200     G6=G4+G5
28.300     G7=K7
29.000     G3=G1+G2+G3+G6
29.200     G9=G3+G7
30.000 C    CENTER SECTION WEIGHT CALCULATIONS
31.000     PLX=MR1TL/HL
32.000     PLY=MLTR2/HL
33.000     AX=PLY/FAL
34.000     AY=PLY/FAL
35.000     G10=(AX+AY)*1.23*RH0L*(LI-Y)
36.000     TBYT=(TR2 TR1/(B*HL))*(1./TAUS)
37.000     IF(TBYT.LE.TMIN) TBYT=TMIN
38.000     TBY=(SLTR2/HL)*(1./TAUS)
39.000     IF(TBY.LE.TBYT) TBY=TBYT
40.000     TBX=(SR1TL/HL)*(1./TAUS)
41.000     IF(TBX.LE.TMIN) TBX=TMIN
42.000     TBAVG=(TBY+TBX)/2.
43.000     G11=TBAVG*(LI-Y)*(2.*HL+B)*RH0S*1.23
43.100 C    CENTER SECTION FRAME CALCULATION
44.000     CF=1./16000.

```

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TABLE 3.2-4  
PROGRAM LISTING (Continued)

```

45.000 PF=6.0
46.000 XCSEC=(6.0*CF*MLIR2*B**2.)/(LFS*EF*DF**2.)
47.000 WBM=YCSEC*(P+2.*HF)*RHOF/LFS
48.000 SXCSEC=(3.*DELP*HL*HL*LFS)/(DF*FAF*3.)
49.000 EXCSEC=(DELP*B*B*LFS)/(4.*DF*FAF)
50.000 WPP=(SXCSEC*2.*HL+BYCSEC*B)*RHOF/LFS
51.000 IF(WBP.LE.WBM) WBP=WBM
52.000 G12=WBP*(LI-Y)*1.23
53.000 C CENTER SECTION BULKHEAD CALCULATION
54.000 G13=RHCB*((P1/(2.*FAB))*(4.*HF+2.*P)
54.100 I+(P1*B/(2.*TAUR)))*1.23
55.000 G14=RHCB*((R2/(2.*FAB))*(4.*HF+2.*P)
55.100 I+(R2*B/(2.*TAUP)))*1.23
55.200 G15=G13+G14
56.000 G16=K2*300.
56.100 C CENTER SECTION WING PROVISION CALCULATION
57.000 G17=.3*(CLAWT*.001*WN7)*(WP/COS(THETA/57.2957))*1.01
57.200 G13=G10+G11+G12+G15+G16+G17
58.000 C CENTER SECTION DOOR CALCULATION
59.000 G19=1.535*SCD
60.000 G20=1.03*(LI-Y)*K3
61.000 G21=660.
61.200 G22=G20+G21
62.000 G23=K4
63.000 G24=G13+G19+G22+G23
64.000 C COVER CALCULATIONS
64.100 C COVER SHELL CALCULATION
65.000 G25=SAW*TBVVG*RHCS*144.*1.23*1.3
65.100 C COVER FRAME CALCULATION
67.000 G26=220.*WBP*(2.*HF+2.*B)/(2.*HL+B)*1.23*1.3
67.000 C COVER LONGERON CALCULATION
69.000 G27=110.*AV*RHCL*P.*1.23*1.3
70.000 G23=G25+G26+G27
71.000 C THRUST STRUCTURE CALCULATIONS
72.000 C THRUST POST
73.000 LE=(LTV**2+HTV**2)**.5
74.000 FTP=ET*.00395
75.000 G29=(P/FTP)*LE*RHSTP*DFAC*2.
76.000 C THRUST GIMBAL PLANE BULKHEAD
77.000 G30=RHCPB*((P*SIN(AGI/57.2957)/(2.*FAB)*DFAC*FS)*(4.*HF+
2.*B)
77.100 I+(P*SIN(AGI/57.2957)*B/(2.*TAUPB)))*2.
79.000 G31=K5*200.
80.000 G32=G29+G30+G31
81.000 G33=K6
82.000 G34=6.7*(PV*.001)**.6
83.000 G35=G25+G26+G27+G32+G34
84.000 G36=G35+G33
84.010 G37=G2+G24+G36

```



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TABLE 3.2-4  
PROGRAM LISTING (Continued)

```

35.000      WRITE(103,100) G37
36.000      WRITE(103,200)
37.000      WRITE(103,300) G1,G11,G25,G10,G07,G12,G26,G15
38.000      1,G2,G3,G6,G16,G17,G32,G34
39.000      WRITE(103,400) G7,G13,G35
90.000      WRITE(103,500)
91.000      WRITE(103,600) G18,G22
91.500      WRITE(103,650) G7,G23,G33
92.000      WRITE(103,700) G9,G24,G36
93.000      100  FORMAT(//,6X,'BODY GROUP',40X,F10.0)
94.000      200  FORMAT(/,30X,'FWD',10X,'CTR',10X,'AFT',/,6X,'BASIC STRUCT
95.000      300  FORMAT(7X,'SIDEWALLS',10X,F10.0,5X,F10.0,5X,F10.0
96.000      1,/,7X,'LONGERONS',25X,F10.0,5X,F10.0
97.000      2,/,7X,'FRAMES',25X,F10.0,5X,F10.0
98.000      3,/,7X,'BULKHEADS',25X,F10.0
99.000      4,/,7X,'CREW OPT. PRGM.',4X,F10.0
100.000     5,/,7X,'WINDSHIELD PRGM.',3X,F10.0
101.000     6,/,7X,'NOSE WUL. WELL PRGM',F10.0
102.000     7,/,7X,'PAYLOAD REACTION',10X,F10.0
103.000     8,/,7X,'WING CARRY THRU.
104.000     9,/,7X,'WING SHEAR PRGM.',13X,F10.0
105.000     1,/,7X,'THRUST STRUCTURE',33X,F10.0
106.000     2,/,7X,'TAIL PRGM.',38X,F10.0)
107.000     400  FORMAT(6Y,'SUB TOTAL',11X,F10.0,5X,F10.0,5X,F10.0)
108.000     500  FORMAT(6Y,'SECONDARY STRUCTURE')
109.000     600  FORMAT(7X,'CARGO DOOR SHELL',13X,F10.0
110.000     1,/,7X,'CARGO DOOR MECH.',12X,F10.0)
111.000     650  FORMAT(6Y,'MISC.',15X,F10.0,5X,F10.0,5X,F10.0)
112.000     700  FORMAT(6Y,'TOTAL',15X,F10.0,5X,F10.0,5X,F10.0)
113.000      GO TO 1
114.000     9999 CALL CLOSE1
115.000      STOP
116.000      END
-- HIT AFTER 116.

```



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3.3 Thermal Protection System Weights - This section on the thermal protection system (TPS) is presented for informational purposes only. It was determined that the magnitude of input parameters required to define the isothermal boundaries in the Stacked Pods Program was not justified in view of the fact that the unit TPS weights for these areas are generated outside the program. Therefore, the TPS model in the Orbiter vehicle module consists of input unit weights, and their corresponding areas derived by the user outside of the program. The TPS model is identical to that described by the flow diagram, Figure 3.3-17 in Section 3.3.5, TPS model, for the option of externally derived areas. It includes the iteration technique on the unit weight to account for changes in heating due to changes in the vehicle reentry weight.

3.3.1 General Stacked Pod Theory - The Stacked Pod Method is presented as a tool for determining the surface area of an orbiter. In addition to the primary objective of determining surface areas, the program will calculate volumes, area center of gravity, and volumetric center of gravities. The method is based on the theory that any solid can be described as a stack of pods with their sum of the volumes equal to the volume of the total solid. Likewise, the sum of the surface areas of the pods less the overlap area (shaded subtractions on Figure 3.3-1) is equal to the surface area of the total solid.

The pods are described to the computer in terms of changes at inflection points. These changes may be in reference to shape, width, depth, or redundancy (overlaps area dimension). Figure 3.3-2 displays the plan and profile silhouettes of a pod to be input into the computer in terms of eight inflection points.

Every inflection point will have an associated horizontal location to assure that all inflection points of all pods are properly located in the fore and aft direction. Vertical and lateral locations are ignored. For example, if an added pod was described to the computer, the program would not know or care if this pod was on the top, bottom, or side of the pod to which it was added, but rather that it started at some horizontal coordinate and continued to some ending horizontal coordinate.

This program enables the user to introduce dissimilar shapes at inflection points and to have accurate mathematics to calculate surface area and volumetric data. There are 18 basic shapes programmed into the routine, Figures 3.3-3 and 3.3-4.

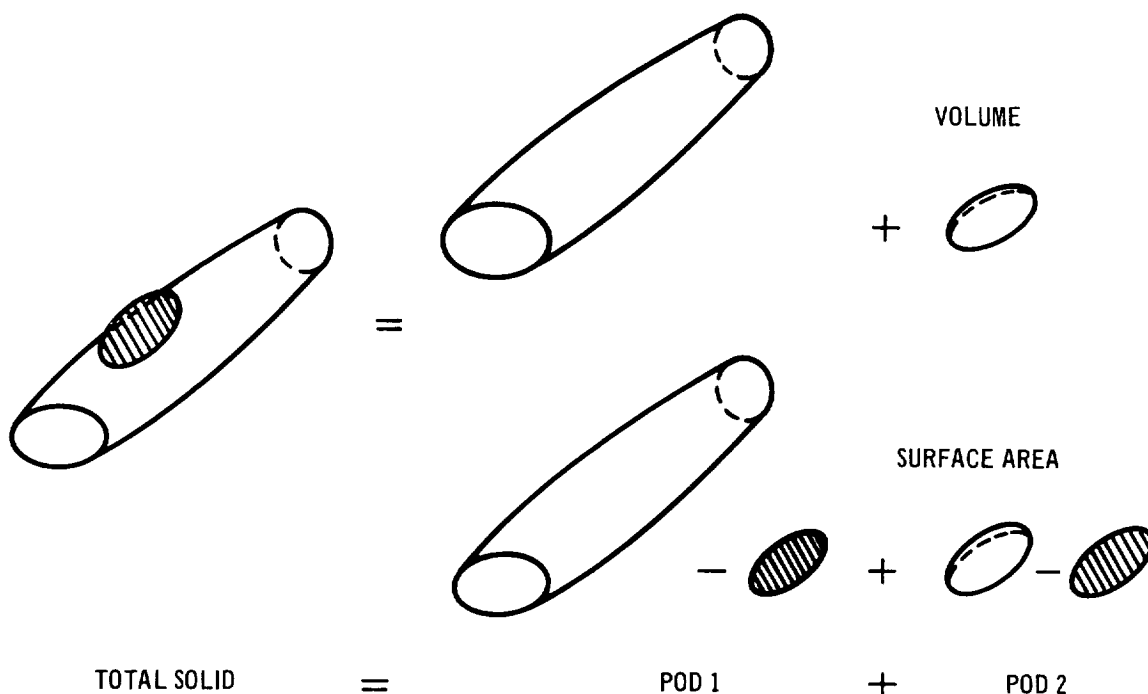


FIGURE 3.3-1 GEOMETRIC EQUIVALENCE OF POD STACKING

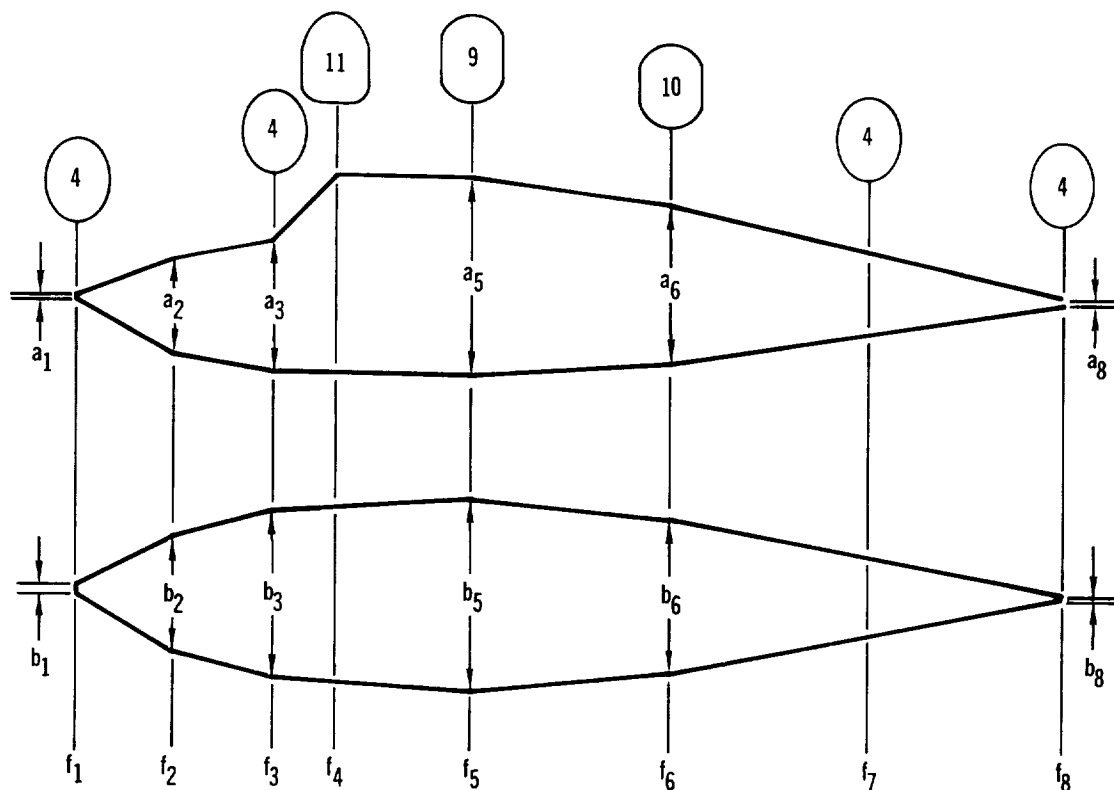


FIGURE 3.3-2 SILHOUETTE TRANSFORM TO COMPUTERIZED INFLECTION POINTS

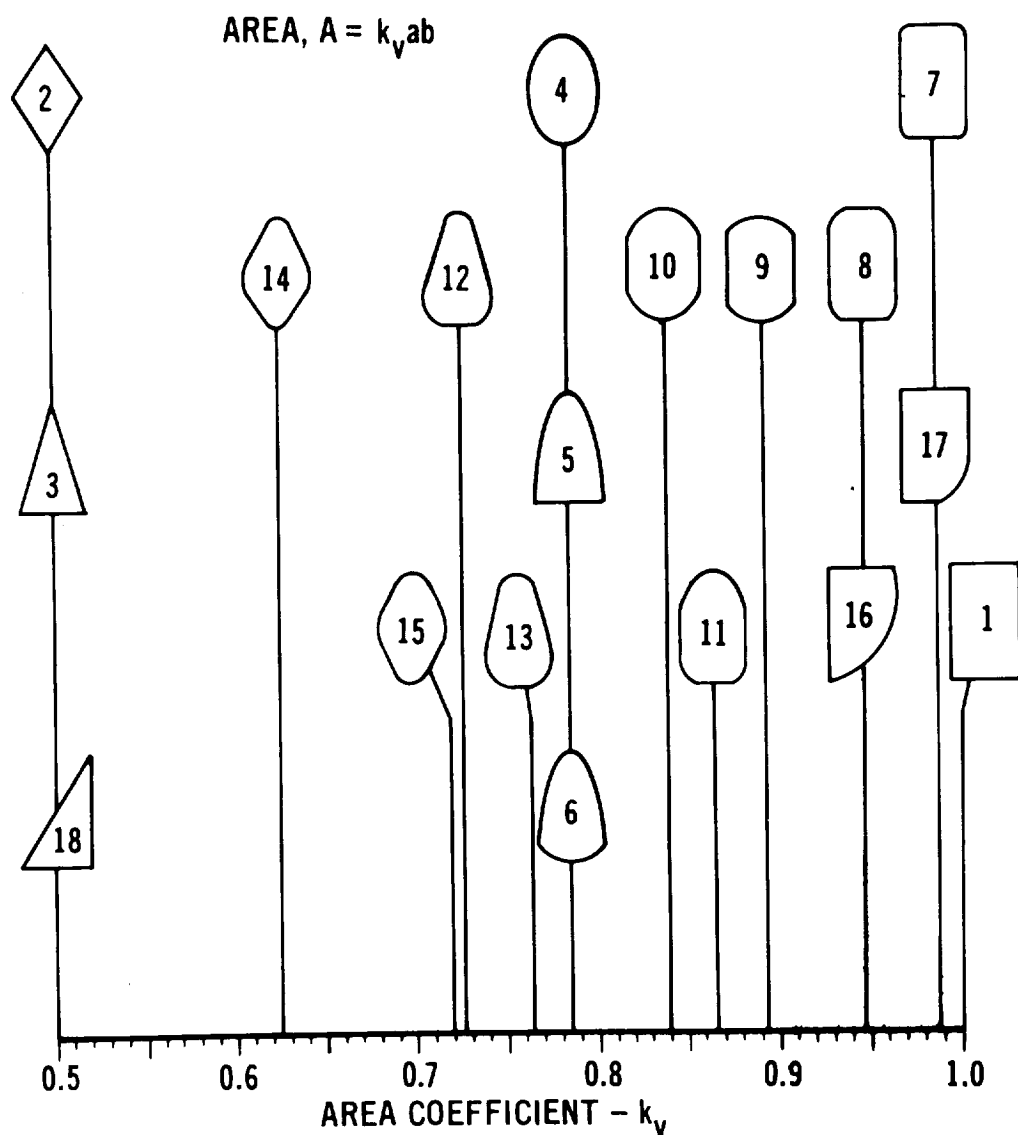


FIGURE 3.3-3 AREA COEFFICIENT AS A FUNCTION OF SHAPE CODE

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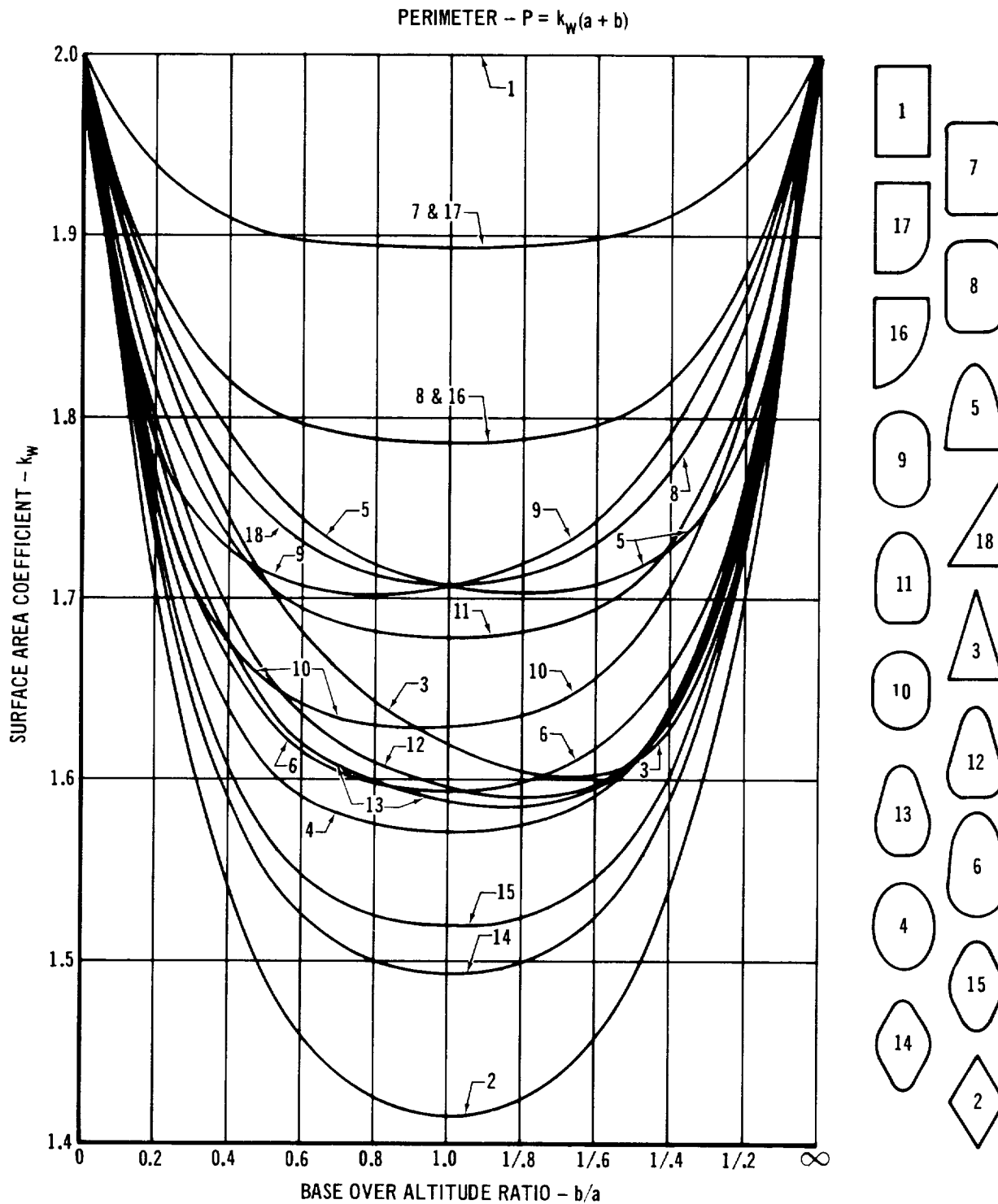


FIGURE 3.3-4 PERIMETER COEFFICIENT VALUES

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All shapes are a composite of straight lines and/or elliptical segments. The transition of lines is either continuous (smoothly faired) or discontinuous (sharp angled). Shapes 4, and 6 through 15 are totally continuous, while shapes 1, 2, 3, and 18 are totally discontinuous in type of transition. Shapes 5, 16, and 17 have both types.

While all shapes have exact mathematical relationships as to the length of the curved and straight elements they contain, the intent is for sight identification. By supplying the maximum dimensions of the width (b) and depth (a), the mathematical relationships of the shape will derive the area and perimeter. For surface area calculation, it is necessary to remove the overlap area by removing the redundant perimeter, the shaded area in Figure 3.3-1.

For a shape code, the program calculates coefficients  $k_v$  for computing cross-sectional areas and pod volumes, and  $k_w$  for computing cross-sectional perimeters and pod surface areas. Multiplier  $k_v$  is used to compute the cut area (A) by the formula

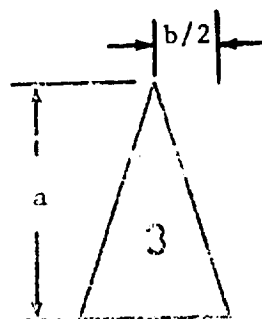
$$A = k_v ab$$

for known height or depth (a) and base or width (b). Figure 3.3-3 is a display of  $k_v$  as a function of shape code. Likewise, the cut perimeter (P) is a function of  $k_w$ :

$$P = k_w (a + b).$$

Figure 3.3-4 displays the  $k_w$  for each shape code as a function of ratio b/a.

The derivation of these multiplier coefficients ( $k_w$ ,  $k_v$ ) is straightforward, and is illustrated below for two shapes.



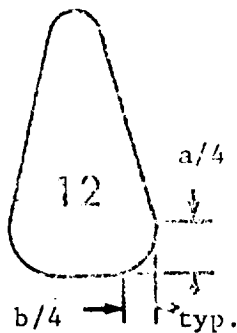
$$k_{v3} = \frac{1/2 ab}{ab} = 0.50$$

$$k_{w3} = \frac{b + 2(a^2 + b^2/4)^{1/2}}{a + b}$$

$$= \frac{\frac{b}{a} + \left[ \left( \frac{b}{a} \right)^2 + 4 \right]^{1/2}}{b/a + 1}$$

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$$k_{v12} = \frac{\pi \left(\frac{a}{4}\right) \left(\frac{b}{4}\right) + \left[ \frac{b}{4} + \frac{b}{2} + 2\delta_1 \left(\frac{b}{4}\right) \right] \left(\frac{a}{2}\right) + \left(\frac{a}{4}\right) \left(\frac{b}{2}\right)}{ab} = 0.726$$

$$k_{w12} = \frac{\frac{b}{2} + 2 \left[ \frac{a^2}{4} + \frac{b^2}{16} \right]^{1/2}}{a + b} + k_{w4} \left( \frac{a}{2} + \frac{b}{2} \right)$$

$$= \frac{1}{2} k_{w3} + \frac{1}{2} k_{w4}$$

Integrating the perimeters and cross-sectional areas over the length of the pod generates the surface areas and volume. Inherent with the integration process is the definition of how the perimeter and cross-sectional area transform from one shape at an inflection cut to another shape at the next inflection cut. The following definition is basic to this analysis.

Every consistently defined segment around a perimeter will linearly map to a point at the next inflection cut if the corresponding segment is dissimilar (holding its shape throughout the mapping). Similar corresponding segments of two adjacent inflection cuts will merely hold their shape. Figure 3.3-5 explains the term "consistently defined segments." Line segments 1-2, 2-3, 3-4, 4-5, 5-6, and 6-1 are consistently defined as they contain only curved or only straight line segments. For example, 1-3 or 2-6 are not consistently defined as they contain both curved and straight line segments.

Figure 3.3-6 explains the term "corresponding segments" for two adjacent cuts. Segments 1-2 and 1-3 correspond to 4-5 and 4-7, respectively, and by definition will merely hold their shape throughout the mapping. Segment 2-3 corresponds to segments 5-6 and 6-7, and these segments will each map to a point on the adjacent inflection cut. Figure 3.3-7 is a display of two possible mappings.

The second basic assumption of this analysis is that the centroid of all cross-sectional areas at inflection points lies along a common reference axis. See Figure 3.3-8.

There are many ways to input the same information to the computer. Figure 3.3-9 displays three possible options for the same information. The middle option is obviously the simplest for this cut, but inflection at other stations could make a single pod 2 option impossible.

The straight line subtractions feed the program the amount of contact perimeter between restacked pods. If the redundancies were not removed, the program would compute the total perimeters of all pods, thus overcalculating the surface



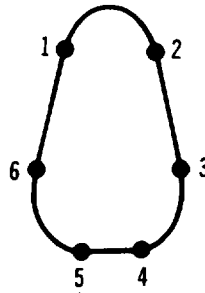


FIGURE 3.3-5 "CORRESPONDING SEGMENTS"  
EXPLANATION

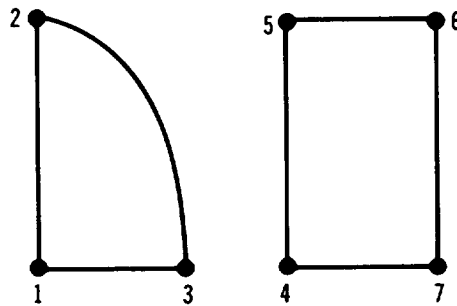


FIGURE 3.3-6 "CONSISTENTLY DEFINED"  
EXPLANATION

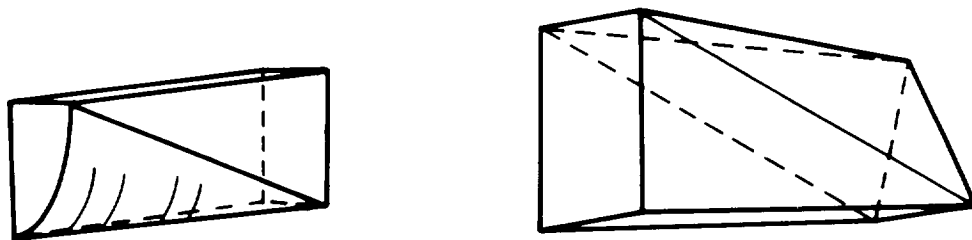


FIGURE 3.3-7 MAPPING DISPLAYS

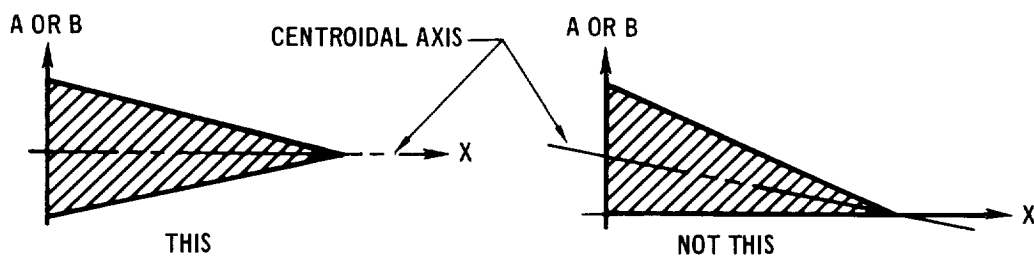


FIGURE 3.3-8 CROSS SECTIONAL AREA CENTROIDAL REQUIREMENT

$$\begin{aligned}
 & \text{Diagram of a four-lobed shape} = \text{Diagram of a vertical oval with '9' inside} - \text{Diagram of a vertical line} + 2X \left( \text{Diagram of a horizontal oval with '5' inside} - \text{Diagram of a horizontal line} \right) \\
 \text{OR} &= \text{Diagram of a vertical oval with '9' inside} - \text{Diagram of a vertical line} + \text{Diagram of a small circle with '4' inside} \\
 \text{OR} &= \text{Diagram of a vertical oval with '9' inside} - \text{Diagram of a vertical line} + 4X \left( \text{Diagram of a horizontal oval with '16' inside} - \text{Diagram of a horizontal line} \right) \\
 \text{TOTAL} &= \text{POD 1} + \text{POD 2}
 \end{aligned}$$

FIGURE 3.3-9 POD EQUIVALENCE OPTIONS

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area. To input the shaded area in Figure 3.3-10 the redundant perimeter is zero at  $f_4$ , and  $r$  at  $f_5$  and  $f_7$ . The program computes the area between the extremes of the redundancy ( $f_4$  and  $f_7$  in the example) by assuming a linear transition from one redundant to the next. This area will be removed from the total surface area.

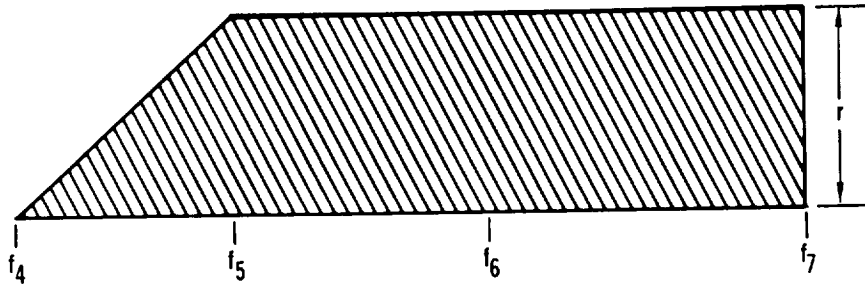


FIGURE 3.3-10 REDUNDANCY INPUT DISPLAY

Added pods respond to both total volume and to total surface area. If one pod is subtracted from another, the routine will respond to the subtracted pod for total volume, but ignore it for total surface area. This allows the determination of the surface area of pods with concave cuts as shown in Figure 3.3-11.

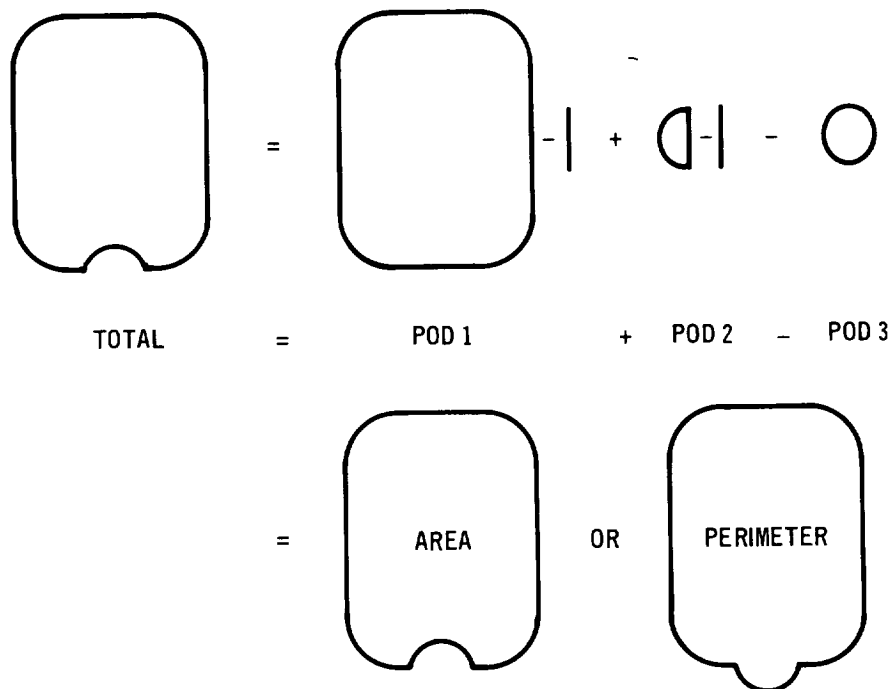


FIGURE 3.3-11 CONCAVE GEOMETRY

The preceding discussion has concerned itself with surface area along the reference axis. In order to generate the total surface area of a pod, there must be the option of excluding or removing front and rear faces. The removing requirement is because surface area responds only to additive pods so there must be the capability of removing face areas when adding a pod to a body.

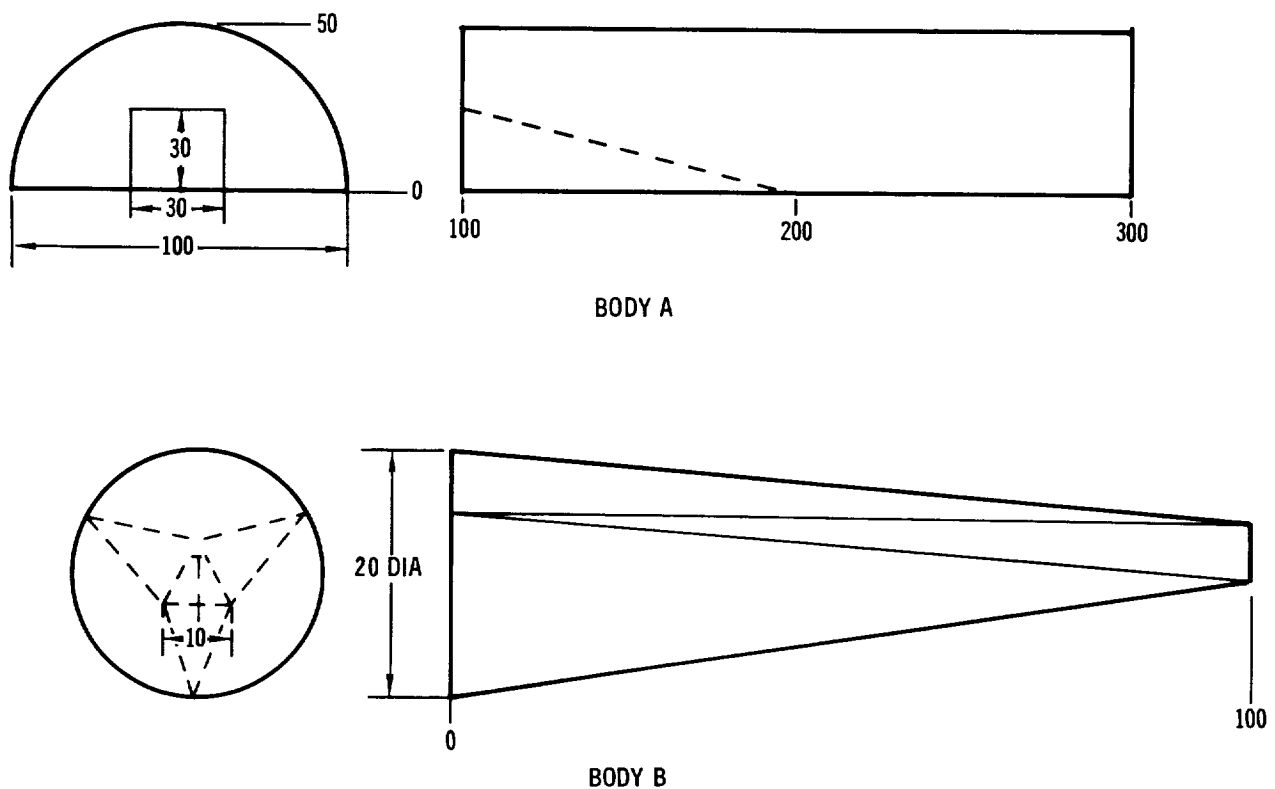


FIGURE 3.3-12 BODY GEOMETRY

3.3.2 Sample Results - An example of body geometry is shown in Figure 3.3-12 with the resulting comparison of program generated data with actual data shown in Table 3.3-1. Table 3.3-2 is a comparison of stacked pods, derived areas and volumes with actual data for a typical Orbiter and the C-5A aircraft. The table notes the variation in percent error as a function of the number of section cuts taken.

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TABLE 3.3-1  
TEST RESULTS

PROGRAM GENERATED - ACTUAL DATA COMPARISON

GROUP NAME	VOLUME FT <sup>3</sup>	VOLUME C.G. IN	SURFACE AREA FT <sup>2</sup>	AREA C.G. IN
BODY A 1)	428.2	204.1	427.0	198.1
2)	428.4	204.1	427.1	198.1
BODY B 1)	10.1	37.3	33.1	44.7
2)	10.1	37.4	33.1	44.7

1) Program generated data

2) Actual data via hand calculations

TABLE 3.3-2  
TEST RESULTS

VEHICLE	WETTED AREA - FT <sup>2</sup>			VOLUME - FT <sup>3</sup>			NO. OF CUTS
	ACTUAL	CALC	PERCENT ERROR	ACTUAL	CALC	PERCENT ERROR	
MDC Shuttle Orbiter	7788	7656	1.7	34,347	34,383	0.1	20
MDC Shuttle Orbiter	7788	7390	5.1	34,347	31,558	8.1	11
MDC Shuttle Orbiter	7788	8461	8.6	34,347	31,393	8.6	6
C-5A*	16646	17052	2.4	86,610	93,816	8.3	40

\*Data taken from 1/150 scale drawing.

3.3.3 Thermal Protection Application - The stacked pod method of calculating areas lends itself ideally to thermal protection calculations. The user can match the pods and inflection points directly with the thermal analysis. Table 3.3-3 shows the TPS analysis for the MDC Shuttle Orbiter, and Figure 3.3-13 shows how these average TPS weights are applied to the configuration.

TABLE 3.3-3  
ORBITER TPS WEIGHT SUMMARY

BODY STATION	AREA (FT <sup>2</sup> )	BASIC		ADHESIVE		NON-OPT		TOTAL		AVG. LB/FT <sup>2</sup>
		LB/FT <sup>2</sup>	WT (LB)	ADH (LB/FT <sup>2</sup> )	WT (LB)	LB/FT <sup>2</sup>	WT (LB)	LB/FT <sup>2</sup>	WT (LB)	
Nose Cap	18	7.62	137.0	0.07	1.0	0.77	14.0	8.46	152.0	4.74
200-240	36	2.54	91.0	0.07	3.0	0.27	10.0	2.88	104.0	
	54								256.0	
Fwd-Upr-St	720	1.66	1195.0	0.17	122.0	0.18	130.0	2.01	1447.0	1.75
364-570	722	1.18	852.0	0.17	123.0	0.14	101.0	1.49	1076.0	
	1442								2523.0	
Bottom										
240-1586	2079	2.53	4260.0	0.17	353.0	0.27	562.0	2.97	6175.0	2.97
Aft-Top										
570-1586	1750	0.94	1645.0	0.17	298.0	0.11	192.0	1.22	2135.0	1.22
Aft-Sid										
570-1586	1600	0.94	1504.0	0.17	272.0	0.11	176.0	1.22	1952.0	1.22
TOTAL	6925								13,041	

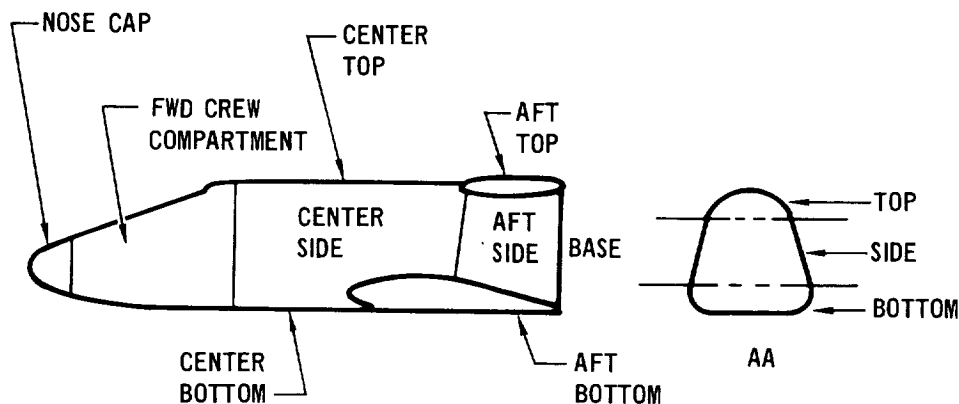


FIGURE 3.3-13 TPS BODY BREAKDOWN

Table 3.3-4 displays the stacked-pod data file and its corresponding output which duplicates the thermal analysis on the MDC Orbiter. Section 3.3-2 demonstrated the accuracy of the stacked pod method as a tool for calculating total areas of geometric shapes and vehicles. Table 3.3-5 demonstrated not only its accuracy, but also its flexibility in breaking down a vehicle into specified sections. This capability of sectioning a vehicle simplified the tasks of applying average unit weights over a vehicle.

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TABLE 3.3-4  
DATA FILE OUTPUT

1.000	ORBITER BASELINE IPS TEST CASE					8
2.000	NOSE CAP 200-240	1	2	1	1	0 4.74
3.000	200.0	0.0	0.0	4	0.0	1
4.000	240.0	70.0	102.0	4	0.0	1
5.000	H TOP FWD ST 364-570	2	4	1	0	0 1.75
6.000	364.0	0.0	0.0	1	0.0	1
7.000	400.0	26.0	88.0	1	88.0	1
8.000	476.0	16.0	120.0	1	120.0	1
9.000	570.0	0.0	0.0	1	0.0	1
10.000	M TOP FWD ST 240-570	2	6	1	0	0 1.75
11.000	240.0	54.0	88.0	7	88.0	1
12.000	300.0	65.0	128.0	7	128.0	1
13.000	364.0	75.0	148.0	7	148.0	1
14.000	400.0	70.0	160.0	7	248.0	1
15.000	476.0	80.0	192.0	7	312.0	1
16.000	570.0	90.0	216.0	7	216.0	1
17.000	SIDE FWD ST 240-570	2	6	1	0	0 1.75
18.000	240.0	54.0	88.0	7	88.0	1
19.000	300.0	105.0	140.0	7	264.0	1
20.000	364.0	150.0	164.0	7	312.0	1
21.000	400.0	145.0	168.0	7	336.0	1
22.000	476.0	160.0	210.0	7	384.0	1
23.000	570.0	180.0	210.0	7	216.0	1
24.000	TOP AFT ST 570-1586	5	6	1	0	0 1.22
25.000	570.0	62.0	216.0	5	216.0	1
26.000	800.0	62.0	216.0	5	216.0	1
27.000	1000.0	62.0	216.0	5	216.0	1
28.000	1200.0	58.0	216.0	5	256.0	1
29.000	1400.0	58.0	216.0	5	256.0	1
30.000	1570.0	0.0	216.0	5	216.0	1
31.000	SIDE AFT ST 570-1586	6	6	1	0	0 1.22
32.000	570.0	144.0	216.0	7	432.0	1
33.000	800.0	128.0	220.0	7	440.0	1
34.000	1000.0	128.0	220.0	7	440.0	1
35.000	1200.0	132.0	220.0	7	440.0	1
36.000	1400.0	178.0	232.0	7	456.0	1
37.000	1570.0	0.0	232.0	7	456.0	1
38.000	BOI FWD ST 240-1586	7	6	1	0	0 2.97
39.000	240.0	0.0	0.0	5	0.0	1
40.000	300.0	6.0	128.0	1	128.0	1
41.000	364.0	10.0	152.0	1	152.0	1
42.000	400.0	12.0	176.0	1	176.0	1
43.000	476.0	12.0	200.0	1	200.0	1
44.000	570.0	16.0	216.0	1	216.0	1
45.000	BOI AFT ST 570-1586	7	6	1	0	0 2.97
46.000	570.0	16.0	216.0	1	216.0	1
47.000	800.0	.001	216.0	1	216.0	1
48.000	1000.0	.001	244.0	1	220.0	1
49.000	1200.0	.001	240.0	1	220.0	1
50.000	1400.0	.001	232.0	1	232.0	1
51.000	1570.0	.001	232.0	1	232.0	1
52.000	*					

--END HIT AFTER 52.

\*

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TABLE 3.3-4  
DATA FILE OUTPUT (Continued)

ORBITER BASELINE TPS TEST CASE

GROUP NAME	VOLUME CU.FT.	VOLUME C.G. IN.	SURFACE AREA SQ.FT.	AREA C.G. IN.	HEIGHT LB.
NOSE CAP 200-240	43.2	230.0	54.2	226.7	54.2
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	1417.8
TOP AFT ST 570-1586	5415.5	1021.5	1731.1	1047.2	1731.1
SIDE AFT ST 570-1586	16390.1	1055.7	1624.4	1069.4	1624.4
BOT FWD ST 240-1586	576.4	532.4	2100.8	946.9	2100.8
TOTAL	29585.3	888.9	6928.3	888.3	6928.3

TABLE 3.3-5  
ACTUAL VERSUS CALCULATED TPS WEIGHTS

BODY STATION	AREA	ACTUAL LB/FT <sup>2</sup>	WT-LB	AREA	CALCULATED LB/FT <sup>2</sup>	WT-LB	ERROR (PERCENT)
Nose Cap 200-240	54	4.74	256.0	54.2	4.74	256.9	+ .4
Fwd-Upr-St 364-570	1442	1.75	2523.0	1417.8	1.75	2481.2	-1.7
Bottom 240-1586	2079	2.97	6175.0	2100.8	2.97	6239.4	+1.0
Aft-Top 570-1586	1750	1.22	2135.0	1731.1	1.22	2111.9	- .1
Aft-Side 570-1586	1600	1.22	1952.0	1624.4	1.22	1981.8	+1.5
Total	6925		13,041.0	6928.3		13,071.2	+ .2



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3.3.4 Program - Table 3.3-6 is a formulaized display of input parameter formats. A brief description of each parameter is also included. Following this table is a listing of the Stacked Pod Computer program (Table 3.3-7).

**TABLE 3.3-6  
INPUT PARAMETERS AND DESCRIPTION PROGRAM MASTER CARD**

FORMAT	COLUMN	NAME	DESCRIPTION
20A2	1-40	NAMEFL	Information to be printed as heading of output data.
I5	41-45	NPD	Total number of pods or Pod Master Cards (15 maximum).
POD MASTER CARD			
10A2	1-20	NAMEPD	Title information for each line on pod volume and surface area data.
I5	21-25	NGR	Successive integers on which pods are totalled for data print out (first pod numbered 1).
I5	26-30	NIF	Number of inflection points or Pod Data Cards to follow each Pod Master Card (not larger than 15).
I5	31-35	NMP	Multiplier so as to include the number of these identical pods used (positive or negative).
I5	36-40	MFO	Forward face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1
I5	41-45	MAF	Rear face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1
POD DATA CARDS			
F10.0	1-10	FS	Reference axis coordinate of pod inflection cut.
F10.0	11-20	A	Maximum depth of pod cut.
F10.0	21-30	B	Maximum width of pod cut.
I5	31-35	ISH	Shape code of pod cut.
F10.0	36-45	RED	Redundant perimeter between this and other pods when restacked.
I5	46-50	ICN	Dummy redundancy integer to establish whether redundant perimeter (zero or greater) is used in redundance analysis.

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TABLE 3.3-7  
DATA FILE

COPY STACKPBD TO LP(K,NC)

1	1.000	FIXED	
2	2.000		COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
3	3.000		1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
4	4.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
5	5.000		3,XVP(20),MFB(20),MAF(20)
6	6.000		DB 20 I=1,20
7	7.000		DB 10 J=1,30
8	8.000		FS(J,I)=0.
9	9.000		A(J,I)=0.
10	10.000		B(J,I)=0.
11	11.000		RED(J,I)=0.
12	12.000		CV(J,I)=0.
13	13.000		CW(J,I)=0.
14	14.000		ISH(J,I)=0
15	15.000	10	ICN(J,I)=0
16	16.000		ZZ(I)=0.
17	17.000		WAP(I)=0.
18	18.000		VLP(I)=0.
19	19.000		XWP(I)=0.
20	20.000		XVP(I)=0.
21	21.000		NMP(I)=0
22	22.000		NIF(I)=0
23	23.000		NGP(I)=0
24	24.000		MFB(I)=0
25	25.000	20	MAF(I)=0.
26	26.000		READ(5,900) NAMEFL,NPD
27	27.000		DB 50 I=1,NPD
28	28.000		READ(5,901)(NAMEPD(J,I),J=1,10),NGP(I),NIF(I),NMP(I),MFB(I),MAF(I)
29	29.000		NIP=NIF(I)
30	30.000		DB 30 K=1,NIP
31	31.000	30	READ(5,902) FS(K,I),A(K,I),B(K,I),ISH(K,I),RED(K,I),ICN(K,I)
32	32.000	50	CONTINUE
33	33.000		DB 90 I=1,NPD
34	34.000		NIP=NIF(I)
35	35.000		DB 60 I=1,NIP
36	36.000	60	ZZ(I)=A(I,I)
37	37.000		CALL ARREFL
38	38.000		DB 70 I=1,NIP
39	39.000		A(I,I)=ZZ(I)
40	40.000	70	ZZ(I)=B(I,I)
41	41.000		CALL ARREFL
42	42.000		DB 80 I=1,NIP
43	43.000	80	B(I,I)=ZZ(I)
44	44.000		CALL HEREYE
45	45.000		CALL CGENER
46	46.000		CALL PBDPBD
47	47.000	90	CONTINUE
48	48.000		JJ=1
49	49.000		JK=2
50	50.000		IF(NPD.LE.1) GO TO 150
51	51.000	100	IF(NGP(JJ).LT,NGP(JK)) GO TO 130
52	52.000		VLP(JJ)=VLP(JJ)+VLP(JK)
53	53.000		XVP(JJ)=XVP(JJ)+XVP(JK)
54	54.000		XWP(JJ)=XWP(JJ)+XWP(JK)
55	55.000		WAP(JJ)=WAP(JJ)+WAP(JK)
56	56.000		VLP(JK)=0.
57	57.000		IF(JK.GE.NPD) GO TO 150
58	58.000		JK=JK+1
59	59.000		GO TO 100

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DATA FILE (Continued)

60	60.000	130	IF(JK.GE.NPD) GO TO 150
61	61.000	140	JJ=JK
62	62.000		JK=JK+1
63	63.000		GO TO 100
64	64.000	150	WRITE(6,903) NAMEFL
65	65.000		TOTL1=0.
66	66.000		TOTL2=0.
67	67.000		TOTL3=0.
68	68.000		TOTL4=0.
69	69.000		DO 190 I=1,NPD
70	70.000		IF(VLP(I).EQ.0.) GO TO 190
71	71.000		XY=XVP(I)/VLP(I)
72	72.000		XZ=XWP(I)/WAP(I)
73	73.000		VLP(I)=VLP(I)/1728.
74	74.000		XVP(I)=XVP(I)/1728.
75	75.000		XWP(I)=XWP(I)/144.
76	76.000		WAP(I)=WAP(I)/144.
77	77.000		WRITE(6,904) (NAMEPD(J,I),J=1,10),VLP(I),XY,WAP(I),XZ
78	78.000		TOTL1=TOTL1+VLP(I)
79	79.000		TOTL2=TOTL2+XVP(I)
80	80.000		TOTL3=TOTL3+XWP(I)
81	81.000		TOTL4=TOTL4+WAP(I)
82	82.000	190	CONTINUE
83	83.000		XY=TOTL2/TOTL1
84	84.000		XZ=TOTL3/TOTL1
85	85.000		WRITE(6,905) TOTL1,XY,TOTL4,XZ
86	86.000	900	FORMAT(20A2,15)
87	87.000	901	FORMAT(10A2,5I5)
88	88.000	902	FORMAT(3F10.0,15,F10.0,15)
89	89.000	903	FORMAT(11'////25X,20A2////10X,1GROUP,18X,1VOLUME,3X,1VOLUME,
90	90.000		1,3X,1SURFACE,15X,1AREA,10X,1NAME,30X,1C.G.,1,6X,1AREA,
91	91.000		5,5X,1C.G.,1,33X,1CU.FT.,1,6X,1IN.,1,4X,1SQ.FT.,1,6X,1IN.,1//)
92	92.000	904	FORMAT(10X,10A2,X,F8.1,F9.1,F10.1,F9.1//)
93	93.000	905	FORMAT(/10X,1TOTAL,13X,F11.1,F9.1,F10.1,F9.1)
94	94.000		STOP
95	95.000		END
96	96.000		SUBROUTINE ARRFIL
97	97.000		COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
98	98.000		1,B(30,20),1SW(30,20),ZZ(30),RED(30,20),1CN(30,20),CV(30,20)
99	99.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
100	100.000		3,XVP(20),MFB(20),MAF(20)
101	101.000		NIP=NIF(1)
102	102.000		N1PL=NIP-1
103	103.000		N1PP=NIP+1
104	104.000		DO 5 I=N1PP,30
105	105.000	5	ZZ(I)=0.
106	106.000		IJK=1
107	107.000		DO 10 I=1,NIP
108	108.000		IF(ZZ(I).LE.0.) GO TO 10
109	109.000		IJK=I
110	110.000		GO TO 15
111	111.000	10	CONTINUE
112	112.000	15	IF(IJK.LE.2) GO TO 35
113	113.000		IJJ=IJK-1
114	114.000		VAL=FS(IJK,1)=FS(1,I)
115	115.000		DO 30 I=2,IJJ
116	116.000		VALL=FS(I,I)=FS(1,I)
117	117.000	30	ZZ(I)=ZZ(IJK)*VALL/VAL
118	118.000	35	IK=IJK+1
119	119.000	40	DO 50 I=IK,N1PL
120	120.000		IF(ZZ(I).GT.0.) GO TO 50

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TABLE 3.3-7  
DATA FILE (Continued)

121	•	121.000		IKK=1
122	•	122.000		GO TO 60
123	•	123.000	50	CONTINUE
124	•	124.000		RETURN
125	•	125.000	60	IKKP=IKK+1
126	•	126.000		IKKL=IKK+1
127	•	127.000		DO 70 J=IKKP,NIP
128	•	128.000		IF(ZZ(J).LE.0.) GO TO 70
129	•	129.000		JK=J
130	•	130.000		GO TO 75
131	•	131.000	70	CONTINUE
132	•	132.000		GO TO 80
133	•	133.000	75	DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
134	•	134.000		ZZ(IKK)=ZZ(IKKL)+DEL*(ZZ(JK)-ZZ(IKKL))
135	•	135.000		IK=IKK+1
136	•	136.000		IF(IK*GE.NIP) RETURN
137	•	137.000		GO TO 40
138	•	138.000	80	VAL=FS(NIP,II)-FS(IKKL,II)
139	•	139.000		IF(VAL.EQ.0.) RETURN
140	•	140.000		DO 85 I=IKK,NIP
141	•	141.000		VALL=FS(NIP,II)-FS(I,II)
142	•	142.000	85	ZZ(I)=ZZ(IKKL)+VALL/VAL
143	•	143.000		RETURN
144	•	144.000		END
145	•	145.000		SUBROUTINE REDEYE
146	•	146.000		COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
147	•	147.000		1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
148	•	148.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
149	•	149.000		3,XVP(20),MFB(20),MAF(20)
150	•	150.000		NIP=NIF(II)
151	•	151.000		LLL=-1
152	•	152.000		DO 15 I=1,NIP
153	•	153.000		IF(ICN(I,II).GT.0) GO TO 10
154	•	154.000		RED(I,II)=-1.
155	•	155.000		GO TO 15
156	•	156.000	10	LLL=LLL+1
157	•	157.000		IKEEP2=1
158	•	158.000	15	CONTINUE
159	•	159.000		IF(LLL.LE.0) RETURN
160	•	160.000		DO 30 I=1,IKEEP2
161	•	161.000		IF(RED(I,II).LT.0.) GO TO 30
162	•	162.000		IKEEP1=1
163	•	163.000		GO TO 35
164	•	164.000	30	CONTINUE
165	•	165.000	35	IK=IKEEP1+1
166	•	166.000		IJ=IKEEP2+1
167	•	167.000	40	DO 50 I=IK,IJ
168	•	168.000		IF(RED(I,II).GE.0.) GO TO 50
169	•	169.000		IKK=I
170	•	170.000		GO TO 60
171	•	171.000	50	CONTINUE
172	•	172.000		RETURN
173	•	173.000	60	IKKP=IKK+1
174	•	174.000		IKKL=IKK+1
175	•	175.000		DO 70 J=IKKP,IKEEP2
176	•	176.000		IF(RED(J,II).LT.0.) GO TO 70
177	•	177.000		JK=J
178	•	178.000		GO TO 75
179	•	179.000	70	CONTINUE
180	•	180.000	75	DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
181	•	181.000		RED(IKK,II)=RED(IKKL,II)+DEL*(RED(JK,II)-RED(IKKL,II))

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DATA FILE (Continued)

182	182.000	IK=IKK+1
183	183.000	IF(IK.LY.IKEEP2) GO TO 40
184	184.000	RETURN
185	185.000	END
186	186.000	SUBROUTINE CGENER
187	187.000	COMMON I,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
188	188.000	1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
189	189.000	2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
190	190.000	3,XVP(20),MFB(20),MAF(20)
191	191.000	ELK(X)=((1.2206*X)+.6455)*X+.146)*X+.9987
192	192.000	NIP=NIF(11)
193	193.000	DO 40 I=1,NIP
194	194.000	IF(ISH(I,11).LE.C*AR.ISH(I,11).GT.18) GO TO 40
195	195.000	IF(A(I,11).LE.0.) A(I,11)=.000001
196	196.000	IF(B(I,11).LE.0.) B(I,11)=.000001
197	197.000	ICTY=ISH(I,11)
198	198.000	GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38),ICTY
199	199.000	21 CV(I,11)=1.
200	200.000	CW(I,11)=2.
201	201.000	GO TO 40
202	202.000	22 CV(I,11)=.5
203	203.000	CW(I,11)=2.*SQRT(A(I,11)*2*B(I,11)*2)/(A(I,11)+B(I,11))
204	204.000	GO TO 40
205	205.000	23 CV(I,11)=.5
206	206.000	CCW=SQRT(4.*A(I,11)*2*B(I,11)*2)
207	207.000	CW(I,11)=(B(I,11)+CCW)/(A(I,11)+B(I,11))
208	208.000	GO TO 40
209	209.000	24 CV(I,11)=.785
210	210.000	X=B(I,11)/A(I,11)
211	211.000	IF(X.GT.1.) X=1./X
212	212.000	CW(I,11)=2.*ELK(X)/(X+1.)
213	213.000	GO TO 40
214	214.000	25 CV(I,11)=.785
215	215.000	XX=B(I,11)/A(I,11)
216	216.000	X=B(I,11)/(2.*A(I,11))
217	217.000	IF(X.GT.1.) X=1./X
218	218.000	CW(I,11)=(XX+ELK(X)*(XX+2.)/(X+1.))/(XX+1.)
219	219.000	GO TO 40
220	220.000	26 CV(I,11)=.785
221	221.000	XX=B(I,11)/A(I,11)
222	222.000	X=2.*B(I,11)/(3.*A(I,11))
223	223.000	IF(X.GT.1.) X=1./X
224	224.000	C1=ELK(X)*(XX+1.5)/(X+1.)
225	225.000	X=2.*B(I,11)/A(I,11)
226	226.000	IF(X.GT.1.) X=1./X
227	227.000	C2=ELK(X)*(XX+.5)/(X+1.)
228	228.000	CW(I,11)=(C1+C2)/(XX+1.)
229	229.000	GO TO 40
230	230.000	27 CV(I,11)=.987
231	231.000	X=B(I,11)/A(I,11)
232	232.000	IF(X.GT.1.) X=1./X
233	233.000	CW(I,11)=1.5+.5*ELK(X)/(X+1.)
234	234.000	GO TO 40
235	235.000	28 CV(I,11)=.946
236	236.000	X=B(I,11)/A(I,11)
237	237.000	IF(X.GT.1.) X=1./X
238	238.000	CW(I,11)=1.+ELK(X)/(X+1.)
239	239.000	GO TO 40
240	240.000	29 CV(I,11)=.893
241	241.000	XX=B(I,11)/A(I,11)
242	242.000	X=2.*B(I,11)/A(I,11)

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DATA FILE (Continued)

243	243.000		IF(X,GT,1) X=1./X
244	244.000		CW(I,I)=(1.+2.*ELK(X)*(XX+.5)/(X+1.))/(XX+1.)
245	245.000		GO TO 40
246	246.000	30	CV(I,I)=.839
247	247.000		XX=B(I,I)/A(I,I)
248	248.000		X=4.*B(I,I)/(3.*A(I,I))
249	249.000		IF(X,GT,1) X=1./X
250	250.000		CW(I,I)=(.5+2.*ELK(X)*(XX+.75)/(X+1.))/(XX+1.)
251	251.000		GO TO 40
252	252.000	31	CV(I,I)=.866
253	253.000		X=B(I,I)/A(I,I)
254	254.000		IF(X,GT,1) X=1./X
255	255.000		CW(I,I)=.5+1.5*ELK(X)/(X+1.)
256	256.000		GO TO 40
257	257.000	32	CV(I,I)=.726
258	258.000		CC=SQRT(4.*A(I,I)**2+B(I,I)**2)
259	259.000		C3=(B(I,I)+CCW)/(A(I,I)+B(I,I))
260	260.000		X=B(I,I)/A(I,I)
261	261.000		IF(X,GT,1) X=1./X
262	262.000		CW(I,I)=.5*C3+ELK(X)/(X+1.)
263	263.000		GO TO 40
264	264.000	33	CV(I,I)=.764
265	265.000		CC=SQRT(4.*A(I,I)**2+B(I,I)**2)
266	266.000		C3=(B(I,I)+CCW)/(A(I,I)+B(I,I))
267	267.000		X=B(I,I)/A(I,I)
268	268.000		IF(X,GT,1) X=1./X
269	269.000		CW(I,I)=C3/3+.4*ELK(X)/(3.*X+3.)
270	270.000		GO TO 40
271	271.000	34	CV(I,I)=.675
272	272.000		C2=2.*SQRT(A(I,I)**2+B(I,I)**2)/(A(I,I)+B(I,I))
273	273.000		X=B(I,I)/A(I,I)
274	274.000		IF(X,GT,1) X=1./X
275	275.000		CW(I,I)=.5*C2+ELK(X)/(X+1.)
276	276.000		GO TO 40
277	277.000	35	CV(I,I)=.719
278	278.000		C2=2.*SQRT(A(I,I)**2+B(I,I)**2)/(A(I,I)+B(I,I))
279	279.000		X=B(I,I)/A(I,I)
280	280.000		IF(X,GT,1) X=1./X
281	281.000		CW(I,I)=C2/3+.4*ELK(X)/(3.*X+3.)
282	282.000		GO TO 40
283	283.000	36	CV(I,I)=.785
284	284.000		X=B(I,I)/A(I,I)
285	285.000		IF(X,GT,1) X=1./X
286	286.000		CW(I,I)=1.*ELK(X)/(X+1.)
287	287.000		GO TO 40
288	288.000	37	CV(I,I)=.946
289	289.000		X=B(I,I)/A(I,I)
290	290.000		IF(X,GT,1) X=1./X
291	291.000		CW(I,I)=1.5+.5*ELK(X)/(X+1.)
292	292.000		GO TO 40
293	293.000	38	CV(I,I)=.5
294	294.000		CW(I,I)=1.*SQRT(A(I,I)**2+B(I,I)**2)/(A(I,I)+B(I,I))
295	295.000	40	CONTINUE
296	296.000		CALL CCFILL
297	297.000		RETURN
298	298.000		END
299	299.000		SUBROUTINE CCFILL
300	300.000		COMMON II,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
301	301.000		1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
302	302.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
303	303.000		3,XVP(20),MFO(20),MAF(20)

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TABLE 3.3-7  
DATA FILE (Continued)

304	•	304.000		NIP=NIF(11)
305	•	305.000		IJK=1
306	•	306.000		IF(CW(1,11).GT.0.) GO TO 40
307	•	307.000		DO 30 J=2,NIP
308	•	308.000		IJK=IJK+1
309	•	309.000		IF(CW(J,11).LT.0.) GO TO 30
310	•	310.000		IJ=IJK+1
311	•	311.000		DO 20 K=1,IJ
312	•	312.000		CW(K,11)=CW(IJK,11)
313	•	313.000	20	CV(K,11)=CV(IJK,11)
314	•	314.000		GO TO 40
315	•	315.000	30	CONTINUE
316	•	316.000		RETURN
317	•	317.000	40	IF(IJK.GE.NIP) RETURN
318	•	318.000		IK=IJK+1
319	•	319.000		IF(CW(IK,11).LE.0.) GO TO 60
320	•	320.000		IJK=IJK+1
321	•	321.000		GO TO 40
322	•	322.000	60	IF(IK.GE.NIP) GO TO 90
323	•	323.000		IKP=IK+1
324	•	324.000		DO 80 I=IKP,NIP
325	•	325.000		IF(CW(I,11).LE.0.) GO TO 80
326	•	326.000		IJJ=I
327	•	327.000		GO TO 110
328	•	328.000	80	CONTINUE
329	•	329.000	90	DO 100 K=IK,NIP
330	•	330.000		CV(K,11)=CV(IJK,11)
331	•	331.000	100	CW(K,11)=CW(IJK,11)
332	•	332.000		RETURN
333	•	333.000	110	NE=IJJ-IK
334	•	334.000		NR=IK-1
335	•	335.000		FP=A(IJK,11)+B(IJK,11)
336	•	336.000		RP=A(IJJ,11)+B(IJJ,11)
337	•	337.000		FM=A(IJK,11)+B(IJK,11)
338	•	338.000		RM=A(IJJ,11)+B(IJJ,11)
339	•	339.000		DELCV=CV(IJK,11)-CV(IJJ,11)
340	•	340.000		DO 145 K=1,NF
341	•	341.000		KK=NR+K
342	•	342.000		XBL=(FS(KK,11)-FS(IJK,11))/(FS(IJJ,11)-FS(IJK,11))
343	•	343.000		XBLM=1.-XBL
344	•	344.000		AX=A(IJK,11)+XBL*(A(IJJ,11)-A(IJK,11))
345	•	345.000		BX=B(IJK,11)+XBL*(B(IJJ,11)-B(IJK,11))
346	•	346.000		CW(KK,11)=(CW(IJK,11)*FP+XBLM*(CW(IJJ,11)*RP+XBL*(AX+BX))
347	•	347.000		ABX=AX+RX
348	•	348.000		IF(DELCV) 120,130,140
349	•	349.000	120	CV(KK,11)=CV(IJJ,11)+XBLM**2*DELCV*FM/ABX
350	•	350.000		GO TO 145
351	•	351.000	130	CV(KK,11)=CV(IJK,11)
352	•	352.000		GO TO 145
353	•	353.000	140	CV(KK,11)=CV(IJK,11)+XBL**2*DELCV*RM/ABX
354	•	354.000	145	CONTINUE
355	•	355.000		IJK=IJJ
356	•	356.000		GO TO 40
357	•	357.000		RETURN
358	•	358.000		END
359	•	359.000		SUBROUTINE PADM8D
360	•	360.000		COMMON 11,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
361	•	361.000		1,B(30,20),TSW(30,20),Z(30),RED(30,20),ICN(30,20),CV(30,20)
362	•	362.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
363	•	363.000		3,XVP(20),MFB(20),MAF(20)
364	•	364.000		NIP=NIF(11)

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TABLE 3.3-7  
DATA FILE

365	•	365.000		NIPL=NIP-1
366	•	366.000		XM=NMP(II)
367	•	367.000		AAP=0.
368	•	368.000		XAP=0.
369	•	369.000		DO 20 I=1,NIPL
370	•	370.000		DAX=FS(I+1,II)-FS(I,II)
371	•	371.000		VL1=A(I,II)*B(I,II)
372	•	372.000		VL2=A(I,II)*B(I+1,II)
373	•	373.000		VL3=A(I+1,II)*B(I,II)
374	•	374.000		VL4=A(I+1,II)*B(I+1,II)
375	•	375.000		IF(CV(I,II).GE.CV(I+1,II)) GO TO 10
376	•	376.000		VLL=DAX*(CV(I+1,II)*(VL2+VL3+2.*VL4)+2.*CV(I,II)*VL1)/6.
377	•	377.000		XVV=DAX**2*(CV(I+1,II)*(VL2+VL3+3.*VL4)+CV(I,II)*VL1)/12.
378	•	378.000		GO TO 15
379	•	379.000	10	VLL=DAX*(CV(I,II)*(2.*VL1+VL2+VL3)+2.*CV(I+1,II)*VL4)/6.
380	•	380.000		XVV=DAX**2*(CV(I,II)*(VL1+VL2+VL3)+3.*CV(I+1,II)*VL4)/12.
381	•	381.000	15	VLP(II)=VLP(II)+VLL
382	•	382.000	20	XVP(II)=XVP(II)+XVV+VLL*FS(I,II)
383	•	383.000		VLP(II)=XM*VLP(II)
384	•	384.000		XVP(II)=XM*XVP(II)
385	•	385.000		IF(NMP(II).LE.0) RETURN
386	•	386.000		DO 45 I=1,NIPL
387	•	387.000		DAX=FS(I+1,II)-FS(I,II)
388	•	388.000		P1=CW(I,II)*(A(I,II)+B(I,II))
389	•	389.000		P2=CW(I+1,II)*(A(I+1,II)+B(I+1,II))
390	•	390.000		WPX=DAX*(P1+P2)/2.
391	•	391.000		XPP=DAX**2*(P1+2.*P2)/6.
392	•	392.000		AREAF=CV(I,II)*A(I,II)*B(I,II)
393	•	393.000		AREAA=CV(I+1,II)*A(I+1,II)*B(I+1,II)
394	•	394.000		WPY=AREAF-AREAA
395	•	395.000		WPP=SQRT(WPX**2+WPY**2)
396	•	396.000		WAP(II)=WAP(II)+WPP
397	•	397.000		XWP(II)=XWP(II)+XPP+WPP/WPX+WPP*FS(I,II)
398	•	398.000		IF(RED(I,II).LT.0.) GO TO 45
399	•	399.000	35	IF(RED(I+1,II).LT.0.) GO TO 45
400	•	400.000		AAP=DAX*(RED(I,II)+RED(I+1,II))/2.
401	•	401.000		XAP=DAX**2*(RED(I,II)/6.+RED(I+1,II)/3.)
402	•	402.000		WAP(II)=WAP(II)-AAP
403	•	403.000		XWP(II)=XWP(II)-XAP-AAP*FS(I,II)
404	•	404.000	45	CONTINUE
405	•	405.000		ENDS=0.
406	•	406.000		ENDMUL=0.
407	•	407.000		IF(MFB(II)) 55,60,50
408	•	408.000	50	ENDS=CV(I,II)*A(I,II)*B(I,II)
409	•	409.000		ENDMUL=ENDS*FS(I,II)
410	•	410.000		GO TO 60
411	•	411.000	55	ENDS=-CV(I,II)*A(I,II)*B(I,II)
412	•	412.000		ENDMUL=ENDS*FS(I,II)
413	•	413.000	60	YET=CV(NIP,II)*A(NIP,II)*B(NIP,II)
414	•	414.000		IF(MAF(II)) 75,80,70
415	•	415.000	70	ENDS=ENDS+YET
416	•	416.000		ENDMUL=ENDMUL+YET*FS(NIP,II)
417	•	417.000		GO TO 80
418	•	418.000	75	ENDS=ENDS+YET
419	•	419.000		ENDMUL=ENDMUL+YET*FS(NIP,II)
420	•	420.000	80	WAP(II)=XM*(WAP(II)+ENDS)
421	•	421.000		XWP(II)=XM*(XWP(II)+ENDMUL)
422	•	422.000		RETURN
423	•	423.000		END



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3.3.5 TPS Model - The TPS model that has been incorporated into the sizing program is in modular form. This allows the user to replace the model with another method of his choosing with a minimum of effort.

The first assumption made in formulating this model was that the unit weights will be derived outside the program based on materials selected, cross range, nonoptimums applied, etc. Typical unit weight for this type of derivation can be seen in Table 3.3-8. These unit weights will then be ratioed as a function of  $\Delta(W/S)^{1/8}$  to account for small changes made to the baseline. Assuming that heating time ( $\theta$ ) is unchanged by small changes in vehicle weight (20 percent or less), the derivation of this ratio is as follows:

The total heating ( $Q$ ) is directly related to the reentry vehicle weight  $\Delta Q \simeq \Delta(W/S)$  as noted in NACA Report 1381. The thermal protection system weight is directly related to the total heating and heating time (AIAA 68-757):

$$\Delta(W_{TPS}) \simeq (Q^{1/8} \theta^{3/8})$$

Thus, for negligible heating time changes, the weight relationship becomes:

$$\Delta(W_{TPS}) \simeq (W/S)^{1/8}$$

through substitution. These derived and adjusted unit weights will then be applied to the appropriate areas of the body.

In order to keep the input data at a minimum, the next logical assumption was to constrain the number of body areas to be considered by this model. All vehicle bodies inputted into this model shall consist of nine sections, Figure 3.3-14. The waterlines distinguishing what is top from what is side from what is bottom are free to be chosen by the user.

There are two methods by which the body areas can be incorporated into this model. The first is by simply inputting areas derived outside the program. The second is to have the program calculate them, implementing the stacked pod method. At a glance, the first method seems totally constrained, allowing little, if any, flexibility. However, there are many ways to input the same information to the computer. Table 3.3-9 displays three possible options for inputting the center section of the body into the model. The second method of area incorporation not only has all the advantage of the stacked pod method, but it also has the added distinct advantage of being able to stretch or shrink the baseline and to reflect these changes in length in the body TPS weight. In order to accomplish this, the

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TABLE 3.3-8  
ORBITER TPS WEIGHTS SUMMARY

BODY STATION	BASIC			ADHESIVE		NON-OPT		TOTAL		AVG
	AREA (FT <sup>2</sup> )	LB/ FT <sup>2</sup>	WT (LB)	ADH LB/FT <sup>2</sup>	WT (LB)	LB/FT <sup>2</sup>	WT (LB)	LB/ FT <sup>2</sup>	WT (LB)	
Nose Cap	18	7.62	137.0	0.07	1.0	0.77	14.0	8.46	152.0	4.75
200-240	36	2.54	91.0	0.07	3.0	0.27	10.0	2.88	104.0	
	54								256.0	
Fwd-Upr& Side	720	1.66	1195.0	0.17	122.0	0.18	130.0	2.01	1447.0	1.75
364-570	722	1.18	852.0	0.17	123.0	0.14	101.0	1.49	1076.0	
	1442								2523.0	
Bottom										2.97
240-1586	2079	2.53	5260.0	0.17	353.0	0.27	562.0	2.97	6175.0	
Aft-Top										1.22
570-1586	1750	0.94	1645.0	0.17	298.0	0.11	192.0	1.22	2135.0	
Aft-Side										1.22
570-1586	1600	0.94	1504.0	0.17	072.0	0.11	176.0	1.22	1952.0	
Base	371		2320.0	0.07	3.0		153.0		2473.0	6.66
FUSELAGE TOTAL	7296								15,514.0	
Wing LE	300	8.44	2532.0	0.07	21.0	0.85	255.0	9.36	2808.0	9.36
Wing Upper + Lower	4774		7628.0		609.0		844.0	1.89	9050.0	1.89
WING TOTAL	5074								11,858	
Tail LE	88	4.12	363.0	0.07	6.0	0.42	37.0	4.61	406.0	4.61
Tail Sides	800	0.95	760.0	0.17	136.0	0.11	88.0	1.23	984.0	1.23
TAIL TOTAL	888								1390.0	
Windshield			250.0				25.0		275.0	
TOTAL TPS	13,258								29,037.0	

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user inputs the body station at which he wishes the stretching or shrinking process to begin along with the length change desired. These changes in body length are assumed to be constant cross-sectional area changes. Table 3.3-10 displays the MDC Orbiter, both stretched and shrunk 20 in.

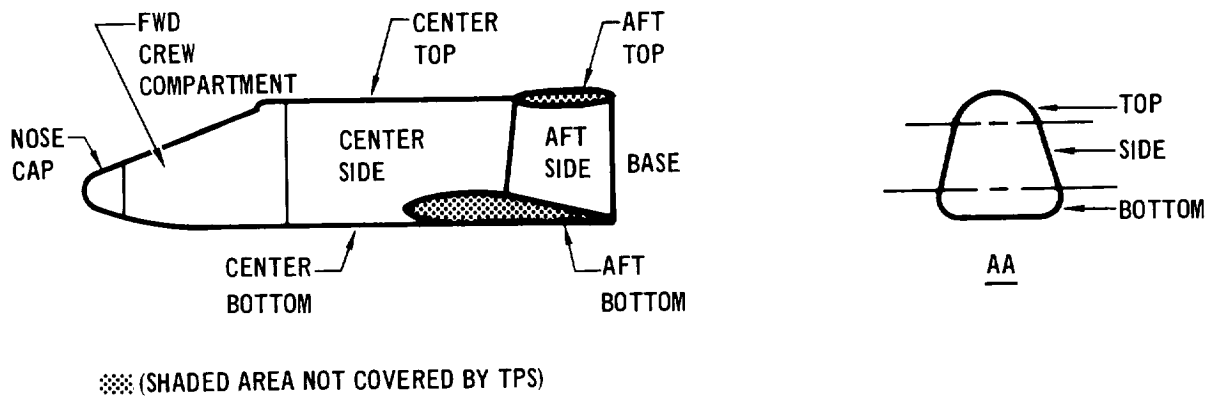


FIGURE 3.3-14 TPS MODEL

TABLE 3.3-9  
TPS INPUT OPTIONS

METHOD	C-TOP AREA (FT <sup>2</sup> )	LB/FT <sup>2</sup>	C-SIDE AREA (FT <sup>2</sup> )	LB/FT <sup>2</sup>	C-BOT AREA (FT <sup>2</sup> )	LB/FT <sup>2</sup>	C-SECT TOT. WT-LB
I	100	1.0	400	1.0	500	1.5	1250
II	0	0	500	1.0	500	1.5	1250
III	0	0	0	0	1000	1.25	1250

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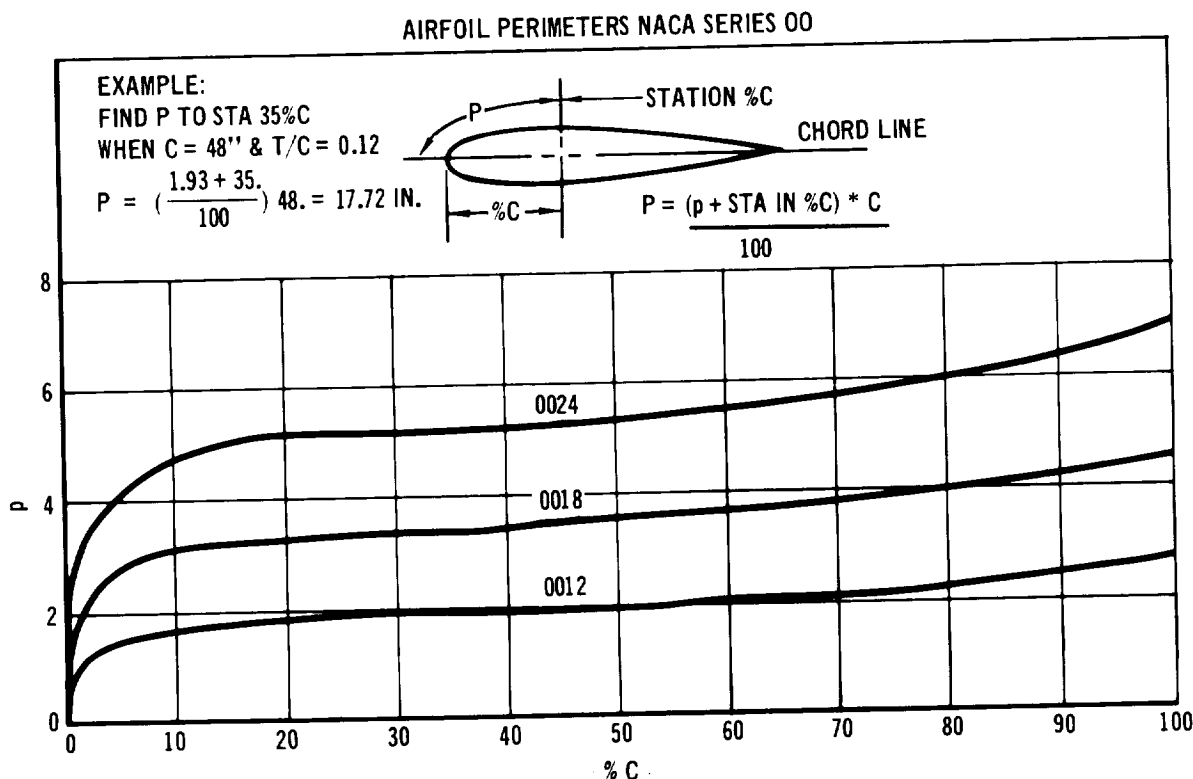
TABLE 3-10  
AREA AND WEIGHT CHANGES DUE TO  $\Delta$  LENGTH  
ORBITER BASELINE TPS TEST CASE

GROUP NAME	VOLUME CU.FT.	VOLUME C.G. IN.	SURFACE AREA SQ.FT.	AREA C.G. IN.	WEIGHT LB
NOSE CAP 200-240	43.2	230.0	54.2	226.7	256.1
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.2
TOP AFT ST 570-1586	5415.5	1021.5	1731.1	1047.2	2111.9
SIDE AFT ST 570-1586	16390.1	1055.7	1624.4	1069.4	1981.8
BOT FWD ST 240-1586	576.4	532.4	2100.8	946.9	6239.4
TOTAL	29585.3	888.9	6928.3	888.3	10001.7
BASELINE SHRUNK 20 IN. FROM B.S. 800					
NOSE CAP 200-240	43.2	230.0	54.2	226.7	256.1
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.2
TOP AFT ST 570-1586	5537.2	1031.3	1768.7	1056.9	2157.8
SIDE AFT ST 570-1586	16728.7	1065.6	1657.1	1079.2	2021.6
BOT FWD ST 240-1586	596.4	539.0	2133.0	957.1	6335.0
TOTAL	30065.6	898.6	7030.8	898.1	10252.5
BASELINE STRETCH 20 IN. FROM B.S. 570					
NOSE CAP 200-240	43.2	230.0	54.2	226.7	256.9
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2481.2
TOP AFT ST 570-1586	5293.8	1011.6	1693.5	1037.6	2066.0
SIDE AFT ST 570-1586	16051.5	1045.9	1591.7	1059.5	1941.9
BOT FWD ST 240-1586	556.4	525.7	2068.6	936.7	6143.8
TOTAL	29105.0	879.3	6825.8	878.5	10000.9

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The third assumption made in this TPS model was that all the aerosurface areas would be calculated outside the module and that they would be input as total projected areas along with their appropriate airfoil constants. These airfoil constants can be obtained from Figure 3.3-15.



**FIGURE 3.3-15 AIRFOIL PERIMETERS**

The perimeter of the airfoil is calculated from the point of intersection of the chord line with the leading edge radius, back to the station in question by taking the value of p from the curves (or by extrapolation) and substituting it in the equation  $P = (p + \text{Sta. in \% C}) \times C$ . To obtain the perimeter between two stations, take the difference in the calculated values of P for each station. After obtaining the total wetted area of the aerosurface in question, the leading edge wetted area is simply a percent of this area. Like the body, the aerosurface area sections have been constrained. Figure 3.3-16 shows the two aerosurface sections considered in this model.

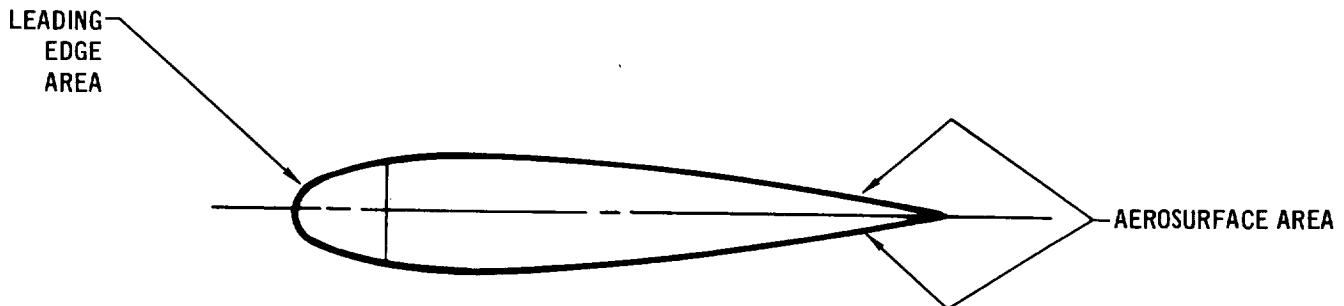


FIGURE 3.3-16 TPS AEROSURFACE BREAKDOWN

The wired in provisions for adding miscellaneous constant weights and a miscellaneous aerosurface control lend additional flexibility to the user who wishes to include such items as windshields, additional aerosurface controls, etc., in the total TPS weight.

Although all TPS weights previously discussed were of an external nature, provisions have been made for the calculation of internal insulation weights. For the sake of simplicity, all the unit weights as well as the areas for the internal insulation weights will be derived outside the program.

Table 3.3-11 is a computer printout of the MDC Orbiter, using inputted body areas while Table 3.3-12 is a printout of the same Orbiter using the stacked pod method. Following the printouts is a copy of the respective data files (Table 3.3-12).

Table 3.3-14 is a formalized display of input parameters required when running a case where the body areas are inputted. Table 3.3-15 is a similar list of parameters required when running a case where the body areas are calculated using the stacked pod methodology. Following this table is a simplified flow diagram (Figure 3.3-17) and a listing of the computer routine (Table 3.3-16).

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TABLE 3.3-11  
ORBITER BASELINE TPS TEST CASE

TPS WEIGHT SUMMARY		
ITEM	AREA	WEIGHT
NOSE CONE	54.	216.
FWD SECT.	1442.	2531.
CT. SECT.	0.	0.
AFT SECT.	5429.	10293.
BASE	371.	2456.
BODY INT. TPS		3476.
CONSTANT		275.
TOTAL BODY		19247.
WING	4774.	9075.
WING LE.	299.	2792.
TOTAL WING		11867.
TAIL	799.	986.
TAIL LE.	88.	406.
TOTAL TAIL		1392.
MIS C. S.	0.	0.
LAND+DOCK TPS		300.
PROP. TPS		1382.
PRIME PWR TPS		89.
HYDRAULIC TPS		77.
SURF. CONT. TPS		118.
TOTAL TPS		34472.

1.000	1	4280.0	0.0	52.0	193525.0		
2.000	ORBITER BASELINE TPS TEST CASE						
3.000	4.74	54.0	1.75	1442.0	0.0	0.0	0.0
4.000	0.00	0.0	0.0	1.22	1750.0	1.22	160
0.							
5.000	2.97	2079.0	6.6	371.0	275.0	1.895	251
1.8							
6.000	.059	9.3	1.23	439.0	.099	4.61	0.0
6.500	0.0	2.02	2.02	0.0	0.0	3476.0	300
7.500	1.0	0.0	0.0	1382.	89.	77.	118
8.500	1.0						
9.500	*						

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TABLE 3.3-11 (Continued)  
ORBITER BASELINE TPS TEST CASE

GROUP NAME	VOLUME CU.FT.	VOLUME C.G. IN.	SURFACE AREA SQ.FT.	AREA C.G. IN.	WEIGHT LB.
NOSE CAP 200-240	43.2	230.0	54.2	226.7	257.7
U TOP FWD ST 364-570	7160.1	439.5	1417.8	425.2	2488.9
TOP AFT ST 570-1586	5415.5	1021.5	1731.1	1047.2	2118.4
SIDE AFT ST 570-1586	16390.1	1055.7	1624.4	1069.4	1987.9
BOT FWD ST 240-1586	576.4	532.4	2100.8	946.9	6258.6
TOTAL	29585.3	888.9	6928.3	888.3	13111.5

TABLE 3.3-12  
TPS WEIGHT SUMMARY

ITEM	AREA	WEIGHT
BODY-BASE		13112.
BASE	371.	2478.
BODY INT. TPS		3476.
CONSTANT		275.
TOTAL BODY		19341.
WING	4774.	9076.
WING LE.	299.	2811.
TOTAL WING		11886.
TAIL	800.	987.
TAIL LE.	88.	407.
TOTAL TAIL		1394.
MIS C. S.	0.	0.
LAND+DOCK TPS		300.
PROP. TPS		1382.
PRIME PWR TPS		89.
HYDRAULIC TPS		77.
SURF. CONT. TPS		119.
TOTAL TPS		34538.



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TABLE 3.3-13  
INPUT PARAMETERS

	0.200	0 4280.0	0.0	52.0	193525.0			
	0.300 6.66	371.0	275.0	1.895	2511.8	.059	9.3	
6	0.310 1.23	439.6	.099	4.61	0.0	0.0	2.0	
2	0.320 2.02	0.0	0.0	3476.0	300.	1.0	0.0	
	0.340 0.0	1382.	89.	77.	118.	1.0		
	0.500	0 20.0	570.0	800.0				
	1.000	ORBITER BASELINE TPS TEST CASE				8		
	2.000	NOSE CAP 200-240			1 2	1 1	0 4.74	
	3.000	200.0	0.0	0.0	4 0.0		1	
	4.000	240.0	70.0	102.0	4 0.0		1	
	5.000	U TOP FWD ST 364-570			4 1 0	0 1.75		
	6.000	364.0	0.0	0.0	1 0.0		1	
	7.000	400.0	26.0	88.0	1 88.0		1	
	8.000	476.0	16.0	120.0	1 120.0		1	
	9.000	570.0	0.0	0.0	1 0.0		1	
	10.000	N TOP FWD ST 240-570			2 6 1 0	0 1.75		
	11.000	240.0	54.0	88.0	7 88.0		1	
	12.000	300.0	65.0	128.0	7 128.0		1	
	13.000	364.0	75.0	148.0	7 148.0		1	
	14.000	400.0	70.0	160.0	7 248.0		1	
	15.000	476.0	80.0	192.0	7 312.0		1	
	16.000	570.0	90.0	216.0	7 216.0		1	
	17.000	SIDE FWD ST 240-570			2 6 1 0	0 1.75		
	18.000	240.0	54.0	88.0	7 88.0		1	
	19.000	300.0	105.0	140.0	7 264.0		1	
	20.000	364.0	150.0	164.0	7 312.0		1	
	21.000	400.0	145.0	168.0	7 336.0		1	
	22.000	476.0	160.0	210.0	7 384.0		1	
	23.000	570.0	180.0	210.0	7 216.0		1	
	24.000	TOP AFT ST 570-1586			5 6 1 0	0 1.22		
	25.000	570.0	62.0	216.0	5 216.0		1	
	26.000	800.0	62.0	216.0	5 216.0		1	
	27.000	1000.0	62.0	216.0	5 216.0		1	
	28.000	1200.0	58.0	216.0	5 256.0		1	
	29.000	1400.0	58.0	216.0	5 256.0		1	
	30.000	1570.0	0.0	216.0	5 216.0		1	
	31.000	SIDE AFT ST 570-1586			6 6 1 0	0 1.22		
	32.000	570.0	144.0	216.0	7 432.0		1	
	33.000	800.0	128.0	220.0	7 440.0		1	
	34.000	1000.0	128.0	220.0	7 440.0		1	
	35.000	1200.0	132.0	220.0	7 440.0		1	
	36.000	1400.0	178.0	232.0	7 456.0		1	
	37.000	1570.0	0.0	232.0	7 456.0		1	
	38.000	BOT FWD ST 240-1586			7 6 1 0	0 2.97		
	39.000	240.0	0.0	0.0	5 0.0		1	
	40.000	300.0	6.0	128.0	1 128.0		1	
	41.000	364.0	10.0	152.0	1 152.0		1	
	42.000	400.0	12.0	176.0	1 176.0		1	
	43.000	476.0	12.0	200.0	1 200.0		1	
	44.000	570.0	16.0	216.0	1 216.0		1	
	45.000	BOT AFT ST 570-1586			7 6 1 0	0 2.97		
	46.000	570.0	16.0	216.0	1 216.0		1	
	47.000	800.0	.001	216.0	1 216.0		1	
	48.000	1000.0	.001	244.0	1 220.0		1	
	49.000	1200.0	.001	240.0	1 220.0		1	
	50.000	1400.0	.001	232.0	1 232.0		1	
	51.000	1570.0	.001	232.0	1 232.0		1	
	52.000 *							

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TABLE 3.3-14  
CARD INPUT FORMAT USING INPUTTED AREAS

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
1st Card				
20A2	1-40	NAMEFL	Information to be printed out as heading.	N D
IS	1-5	SPDM	Counter for area calculations 1 Inputted area 0 Stacked pod areas	N D
F10.0	6-15	SWI	Initial baseline projected area	FT <sup>2</sup>
F10.0	16-25	SWC	Projected area resulting from change to baseline	FT <sup>2</sup>
F10.0	26-35	WSI	Baseline W/S on which TPS unit weights are based	LB-FT <sup>2</sup>
F10.0	36-45	ØLLTPS	Orbiter landing weight less orbiter TPS weight	LB
2nd Card				
F10.0	1-10	NCTPS	Nose cap TPS unit weight	LB-FT <sup>2</sup>
F10.0	11-20	NCA	Nose cap area	FT <sup>2</sup>
F10.0	21-30	FWDTPS	Forward crew compartment TPS unit weight	LB-FT <sup>2</sup>
F10.0	31-40	FWDA	Forward crew compartment area	LB-FT <sup>2</sup>
F10.0	41-50	CTTPS	Center top TPS unit weight	LB-FT <sup>2</sup>
F10.0	51-60	CTA	Center top area	FT <sup>2</sup>
F10.0	61-70	CSTPS	Center side TPS unit weight	LB-FT <sup>2</sup>
3rd Card				
F10.0	1-10	CSA	Center side area	FT <sup>2</sup>
F10.0	11-20	CBTPS	Center bottom TPS unit weight	LB-FT <sup>2</sup>
F10.0	21-30	CBA	Center bottom area	FT <sup>2</sup>
F10.0	31-40	ATTPS	Aft top TPS unit weight	LB-FT <sup>2</sup>
F10.0	41-50	ATA	Aft top area	FT <sup>2</sup>
F10.0	51-60	ASTPS	Aft side TPS unit weight	LB-FT <sup>2</sup>
F10.0	61-70	ASA	Aft side area	FT <sup>2</sup>
4th Card				
F10.0	1-10	ABTPS	Aft bottom TPS unit weight	LB-FT <sup>2</sup>
F10.0	11-20	ABA	Aft bottom area	FT <sup>2</sup>
F10.0	21-30	BASTPS	Base TPS unit weight	LB-FT <sup>2</sup>
F10.0	31-40	BASA	Base area	FT <sup>2</sup>

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TABLE 3.3-14  
CARD INPUT FORMAT USING INPUTTED AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
F10.0	41-50	TPSCON	TPS constant weight (windshield, etc.)	LB
F10.0	51-60	WGTPS	Wing TPS unit weight	LB-FT <sup>2</sup>
F10.0	61-70	WGA	Wing total projected area	FT <sup>2</sup>
5th Card				
F10.0	1-10	WGPLE	Percent of wing total wetted area that is leading edge	%
F10.0	11-20	WLETPS	Wing leading edge TPS unit weight	LB-FT <sup>2</sup>
F10.0	21-30	TLTPS	Tail TPS unit weight	LB-FT <sup>2</sup>
F10.0	31-40	TLA	Tail total projected area	FT <sup>2</sup>
F10.0	41-50	TLPLE	Percent of tail total wetted area that is leading edge	%
F10.0	51-60	TLETPS	Tail leading edge TPS unit weight	LB-FT <sup>2</sup>
F10.0	61-70	MCSTPS	Miscellaneous control surface TPS unit weight	LB-FT <sup>2</sup>
6th Card				
F10.0	1-10	MCSA	Miscellaneous control surface area	FT <sup>2</sup>
F10.0	11-20	WACON	Airfoil perimeter conversion factor	N D
F10.0	21-30	TACON	Airfoil perimeter conversion factor	N D
F10.0	31-40	IBA	Internal body TPS area	FT <sup>2</sup>
F10.0	41-50	IBTPS	Internal body TPS unit weight	LB-FT <sup>2</sup>
F10.0	51-60	IBC	Internal body TPS weight input constant	LB
F10.0	61-70	LDA	Landing and docking TPS area	FT <sup>2</sup>
7th Card				
F10.0	1-10	LDTPS	Landing and docking unit weight	LB-FT <sup>2</sup>
F10.0	11-20	PROA	Propulsion TPS Area	FT <sup>2</sup>
F10.0	21-30	PROTPS	Propulsion TPS unit weight	LB-FT <sup>2</sup>
F10.0	31-40	PROC	Propulsion TPS weight input constant	LB
F10.0	41-50	PPC	Prime power TPS weight	LB
F10.0	51-60	HYC	Hydraulic TPS weight	LB
F10.0	61-70	SCA	Surface control TPS area	FT <sup>2</sup>
8th Card				
F10.0	1-10	SCTPS	Surface control TPS unit weight	LB-FT <sup>2</sup>

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TABL                      TABLE 3.3-15                      OD AREAS  
CARD INPUT FORMAT USING STACKED POD AREAS

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
1st Card				
20A2	1-40	NAMEFL	Information to be printed out as heading.	N D
IS	1-5	SPDM	Counter for area calculations 1 Inputted area 0 Stacked pod areas	N D
F10.0	6-15	SWI	Initial baseline projected area	FT <sup>2</sup>
F10.0	16-25	SWC	Projected area resulting from change to baseline	FT <sup>2</sup>
F10.0	26-35	WSI	Baseline W/S on which TPS unit weights are based	LB-FT <sup>2</sup>
F10.0	36-45	ØLLTPS	Orbiter landing weight less orbiter TPS weight	LB
2nd Card				
F10.0	1-10	BASTPS	Base TPS unit weight	LB-FT <sup>2</sup>
F10.0	11-20	BASA	Base area	FT <sup>2</sup>
F10.0	21-30	TPSCON	TPS constant weight (windshield, etc.)	LB
F10.0	31-40	WGTPS	Wing TPS unit weight	LB-FT <sup>2</sup>
F10.0	41-50	WGA	Wing total projected area	FT <sup>2</sup>
F10.0	51-60	WGPLE	Percent of wing total wetted area that is leading edge	%
F10.0	61-70	WLETPS	Wing leading edge TPS unit weight	LB-FT <sup>2</sup>
3rd Card				
F10.0	1-10	TUTPS	Tail TPS unit weight	LB-FT <sup>2</sup>
F10.0	11-20	TLA	Tail total projected area	FT <sup>2</sup>
F10.0	21-30	TPLPE	Percent of tail total wetted area that is leading edge	%
F10.0	31-40	TLETPS	Tail leading edge TPS unit weight	LB-FT <sup>2</sup>
F10.0	41-50	MSCTPS	Miscellaneous control surface TPS unit weight	LB-FT <sup>2</sup>
F10.0	51-60	MSCA	Miscellaneous control surface area	FT <sup>2</sup>
F10.0	61-70	WACON	Airfoil perimeter conversion factor	N D
4th Card				
F10.0	21-30	TACON	Airfoil perimeter conversion factor	N D
F10.0	31-40	IBA	Internal body TPS area	FT <sup>2</sup>

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TABLE 3.3-15  
CARD INPUT FORMAT USING STACKED POD AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
F10.0	41-50	IBTPS	Internal body TPS unit weight	LB-FT <sup>2</sup>
F10.0	51-60	IBC	Internal body TPS weight input constant	LB
F10.0	61-70	LDA	Landing and docking TPS area	FT <sup>2</sup>
F10.0	1-10	LDTPS	Landing and docking unit weight	FT <sup>2</sup>
F10.0	11-20	PROA	Propulsion TPS Area	FT <sup>2</sup>
			5th Card	
F10.0	21-30	PROTPS	Propulsion TPS unit weight	LB-FT <sup>2</sup>
F10.0	31-40	PROC	Propulsion TPS weight input constant	LB
F10.0	41-50	PPC	Prime power TPS weight	LB
F10.0	51-60	HYC	Hydraulic TPS weight	LB
F10.0	61-70	SCA	Surface control TPS area	FT <sup>2</sup>
F10.0	1-10	SCTPS	Surface control TPS unit weight	FT <sup>2</sup>
			6th Card	
I5	1-5	SPT	Counter for stretching or shrinking vehicle + Stretch from B.S. BSST 0 No change in vehicle length - Shrink from B.S. BSSK	N D
F10.0	6-15	DIFF	Length vehicle is to be changed (positive number)	IN
F10.0	16-25	BSST	Body station at which you wish to start stretch	IN
F10.0	26-35	BSSK	Body station at which you wish to start shrink	IN
			6th Card	
20A2	1-40	NAMEFL	Information to be printed as heading of output data	N D
I5	41-45	NPD	Total number of pods or Pod Master Cards (15 maximum)	N D
			8th Card	
			POD MASTER CARD	
10A2	1-20	NAMEPD	Title information for each line of pod volume and surface area data.	N D
I5	21-25	NGR	Successive integers on which pods are totalled for data printout (first pod numbered 1)	N D

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TABLE 3.3-15  
CARD INPUT FORMAT USING STACKED POD AREAS (Continued)

FORMAT	COLUMN	NAME	DESCRIPTION	UNITS
I5	26-30	NIF	Number of inflection points or Pod Data Cards to follow each Pod Master Card (not larger than 15)	N D
I5	31-35	NMP	Multiplier so as to include the number of these identical pods used (positive or negative)	N D
I5	36-40	MFO	Forward face of pod as part of total pod surface area: Included in surface area 1 Not included in surface area 0 Removed from surface area -1	N D
F10.0	46-55	TPSUWT	TPS unit weight per pod 9th Card POD DATA CARDS	LB-FT <sup>2</sup>
F10.0	1-10	FS	Reference axis coordinate of pod inflection cut	IN
F10.0	11-20	A	Maximum depth of pod cut	IN
F10.0	21-30	B	Maximum width of pod cut	IN
I5	31-35	ISH	Shape code of pod cut	N D
F10.0	36-45	RED	Redundant perimeter between this and other pods when restacked	IN
I5	46-50	ICN	Dummy redundancy integer to establish whether redundant perimeter (zero or greater) is used in redundance analysis	N D

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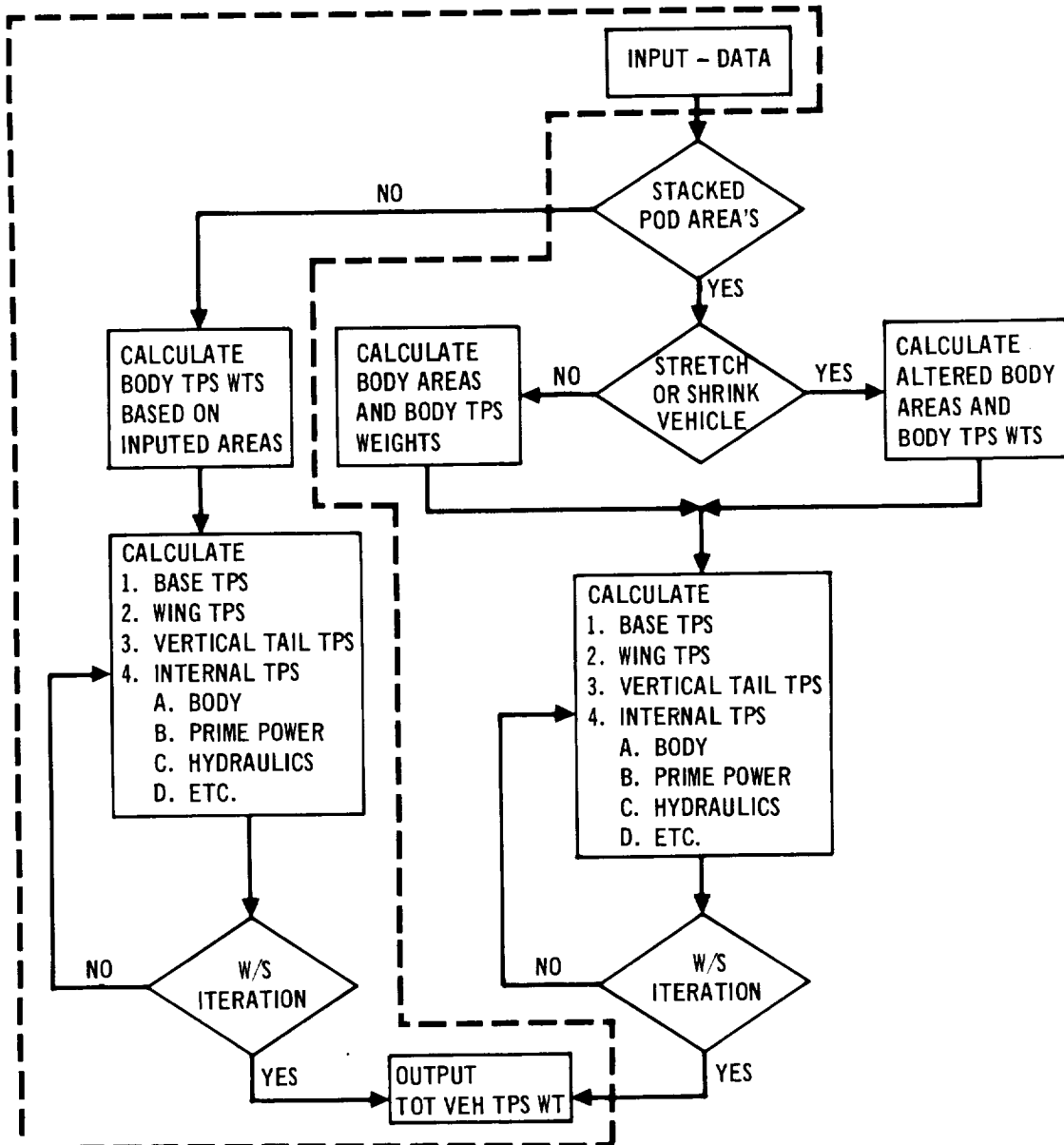


FIGURE 3.3-17 SIMPLIFIED FLOW CHART

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TABLE 3.3-16  
PROGRAM LISTING

COPY TPSPMODEL TO LP(K,NC)

1	1.000	FIXED	
2	2.000		COMMON /I/NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
3	3.000		1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
4	4.000		2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
5	5.000		3,XVP(20),MFB(20),MAF(20),TPSUWT(20),TPSWT(20)
6	6.000		COMMON/III/TATLS,BASA,BASEWT,TPSCBN,BTPSWT,WGTPSA
7	7.000		1,NGWT,WGLEA,WGLEWT,TWGT,TTPSA,TWT,TLEA,TLEWT
8	8.000		2,TTWT,MCSA,MCSTPS,TOTTPS,IBTWT,LDWT,PRWT,PPC
9	9.000		3,HYC,SCWT
10	10.000		INTEGER SPT,SPDM
11	11.000		READ(5,870) SPDM,SWI,SWC,WSI,BLLTPS
12	12.000		TOTTPS=1000.
13	13.000		IF(SPDM,EQ,0) GO TO 5
14	14.000		GO TO 1000
15	15.000	5	READ(5,880) BASTPS,BASA,TPSCBN,WGTPS,WGA,WGLE,WTETPS
16	16.000		READ(5,880) YLTPS,TLA,TLPLE,TLETPS,MCSTPS,MCSA,WACON
17	17.000		READ(5,880) TACBN,IBA,IBTPS,IBC,LDA,LDTPS,PROA
18	18.000		READ(5,860) PROTPS,PROC,PPC,HYC,SCA,SCTPS
19	19.000		DO 20 I=1,20
20	20.000		DO 10 J=1,30
21	21.000		FS(J,I)=0.
22	22.000		A(J,I)=0.
23	23.000		B(J,I)=0.
24	24.000		RED(J,I)=0.
25	25.000		CV(J,I)=0.
26	26.000		CW(J,I)=0.
27	27.000		ISH(J,I)=0
28	28.000	10	ICN(J,I)=0
29	29.000		ZZ(I)=0.
30	30.000		WAP(I)=0.
31	31.000		VLP(I)=0.
32	32.000		XWP(I)=0.
33	33.000		XVP(I)=0.
34	34.000		NMP(I)=0
35	35.000		NIF(I)=0
36	36.000		NGP(I)=0
37	37.000		MFB(I)=0
38	38.000	20	MAF(I)=0
39	39.000		READ(5,890) SPT,DIFF,BSST,BSSK
40	40.000		READ(5,900) NAMEFL,NPD
41	41.000		DO 50 I=1,NPD
42	42.000		READ(5,901)(NAMEPD(J,I),J=1,10),NGP(I),NIF(I),NMP(I),MFB(I),MAF(I)
43	43.000		1,TPSUWT(I)
44	44.000		NIP=NIF(I)
45	45.000		DO 30 K=1,NIP
46	46.000		READ(5,902) FS(K,I),A(K,I),B(K,I),ISH(K,I),RED(K,I),ICN(K,I)
47	47.000		IF(SPT) 38,30,39
48	48.000	3A	IF(FS(K,I),GT,BSSK) FS(K,I)=FS(K,I)+DIFF
49	49.000		GO TO 30
50	50.000	39	IF(FS(K,I),GT,BSST) FS(K,I)=FS(K,I)+DIFF
51	51.000	30	CONTINUE
52	52.000	50	CONTINUE
53	53.000		DO 90 I=1,NPD
54	54.000		NIP=NIF(I)
55	55.000		DO 60 I=1,NIP
56	56.000	60	ZZ(I)=A(I,I)
57	57.000		CALL ARFIL
58	58.000		DO 70 I=1,NIP
59	59.000		A(I,I)=ZZ(I)



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TABLE 3.3-16  
PROGRAM LISTING (Continued)

```

60 * 60.000 70 ZZ(I)=B(I,I)
61 * 61.000 CALL ARRFIL
62 * 62.000 DO 80 I=1,NIP
63 * 63.000 80 B(I,I)=ZZ(I)
64 * 64.000 CALL REDEYE
65 * 65.000 CALL CGENER
66 * 66.000 CALL PBDMD0
67 * 67.000 90 CONTINUE
68 * 68.000 JJ=1
69 * 69.000 JK=2
70 * 70.000 IF(NPD.E.1) GO TO 150
71 * 71.000 100 IF(NGP(JJ).LT.NGP(JK)) GO TO 130
72 * 72.000 VLP(JJ)=VLP(JJ)+VLP(JK)
73 * 73.000 XVP(JJ)=XVP(JJ)+XVP(JK)
74 * 74.000 XWP(JJ)=XWP(JJ)+XWP(JK)
75 * 75.000 WAP(JJ)=WAP(JJ)+WAP(JK)
76 * 76.000 VLP(JK)=0.
77 * 77.000 IF(JK.GE.NPD) GO TO 150
78 * 78.000 JK=JK+1
79 * 79.000 GO TO 100
80 * 80.000 130 IF(JK.GE.NPD) GO TO 150
81 * 81.000 140 JJ=JK
82 * 82.000 JK=JK+1
83 * 83.000 GO TO 100
84 * 84.000 150 WRITE(6,903) NAMEFI
85 * 85.000 SPC=0.0
86 * 86.000 BLANWT=ALLTPS+TSTTPS
87 * 87.000 WSC=BLANWT/(SWI+SWC)
88 * 88.000 155 TLANWT=BLANWT
89 * 89.000 DUWT=(WSC/WSI)**.125
90 * 90.000 TOTL1=0.
91 * 91.000 TOTL2=0.
92 * 92.000 TOTL3=0.
93 * 93.000 TOTL4=0.
94 * 94.000 TOTL5=0.
95 * 95.000 DO 190 I=1,NPD
96 * 96.000 IF(VLP(I).EQ.0.) GO TO 190
97 * 97.000 IF(SPC.EQ.0.) GO TO 157
98 * 98.000 XY=XVP(I)/VLP(I)
99 * 99.000 XZ=XWP(I)/WAP(I)
100 * 100.000 VLP(I)=VLP(I)/1728.
101 * 101.000 XVP(I)=XVP(I)/1728.
102 * 102.000 XWP(I)=XWP(I)/144.
103 * 103.000 WAP(I)=WAP(I)/144.
104 * 104.000 157 TPSWT(I)=WAP(I)+TPSUWT(I)+DUWT
105 * 105.000 IF(SPC.EQ.0.) TPSWT(I)=TPSWT(I)/144.
106 * 106.000 IF(SPC.EQ.0.0) GO TO 160
107 * 107.000 WRITE(6,904) (NAMEPD(J,I),J=1,10),VLP(I),XY,WAP(I),XZ,TPSWT(I)
108 * 108.000 160 TOTL1=TOTL1+VLP(I)
109 * 109.000 TOTL2=TOTL2+XVP(I)
110 * 110.000 TOTL3=TOTL3+XWP(I)
111 * 111.000 TOTL4=TOTL4+WAP(I)
112 * 112.000 TOTL5=TOTL5+TPSWT(I)
113 * 113.000 190 CONTINUE
114 * 114.000 XY=TOTL2/TOTL1
115 * 115.000 XZ=TOTL3/TOTL4
116 * 116.000 IF(SPC.EQ.0.0) GO TO 195
117 * 117.000 WRITE(6,905) TOTL1,XY,TOTL4,XZ,TOTL5
118 * 118.000 195 BASEWT=PASTPS+BASA*DUWT
119 * 119.000 IRTWT=IPA*IRTPS+IRC
120 * 120.000 BTPSWT=TOTL5+BASEWT+TPSCON+IBTWT

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TABLE 3.3-16  
PROGRAM LISTING (Continued)

```

121 • 121.000 C   WING TPS WEIGHT
122 • 122.000     WGWA=WGA*WACON
123 • 123.000     WGLEA=WGWA*WGPLE
124 • 124.000     WGTPSA=WGWA*WGLEA
125 • 125.000     WGWTPSA=WGTPSA*WGTTPS*DUWT
126 • 126.000     WGLEWT=WGLEA*WLTTPS*DUWT
127 • 127.000     TWGWT=WGWTPSA+WGLEWT
128 • 128.000 C   TAIL TPS WEIGHT
129 • 129.000     TWA=TLA*TAACON
130 • 130.000     TLEA=TWA*TLPLE
131 • 131.000     TTPSA=TWA*TLFA
132 • 132.000     TWT=TTPSA*TLTPS*DUWT
133 • 133.000     TLEWT=TLEA*TLTPS*DUWT
134 • 134.000     TTWT=TWT+TLEWT
135 • 135.000     MCSWT=MCSIPS*MCSA*DUWT
136 • 136.000     LDTWT=LDA*LDTPS
137 • 137.000     PRBWT=PRBA*PRBTPS*PRBC
138 • 138.000     SCWT=SCA+SCTPS
139 • 139.000     TBTTPS=RTPSWT+TWGWT+TTWT+MCSWT
140 • 140.000     1+LDTWT+PRBWT+PPC+HYC+SCWT
141 • 141.000     BLANWT=BLLTIPS+TBTTPS
142 • 142.000     WSC=BLANWT/(SWI+SWC)
143 • 143.000     IF (SPC.EQ.1.0) GO TO 1000
144 • 144.000     IF (ABS(TLANWT-BLANWT).LE..1) SPC=1.0
145 • 145.000     GO TO 155
146 • 146.000     840  FORMAT(4F10.0)
147 • 147.000     870  FORMAT(15,4E10.0)
148 • 148.000     880  FORMAT(7F10.0)
149 • 149.000     890  FORMAT(15,3F10.0)
150 • 150.000     900  FORMAT(20A2,15)
151 • 151.000     901  FORMAT(10A2,5I5,F10.0)
152 • 152.000     902  FORMAT(3F10.0,15,F10.0,15)
153 • 153.000     903  FORMAT(11'////25X,20A2///2X,1GROUP!,18X,1VOLUME!,3X,1VOLUME!
154 • 154.000     5,3X,1SURFACE!,5X,1AREA!,5X,1WEIGHT!,2X,1NAME!,30X,1C.G.!
155 • 155.000     5,6X,1AREA!,5X,1C.G.,1/25X,1CU.FT.,6X,1IN.,4X,1SQ.FT.!
156 • 156.000     5,6X,1IN.,6X,1LB.,1//)
157 • 157.000     904  FORMAT(2X,10A2,X,F9.1,F9.1,F9.1,F9.1,F9.1,F9.1/)
158 • 158.000     905  FORMAT(2X,1TOTAL!,13X,F11.1,F9.1,F10.1,F9.1,F9.1)
159 • 159.000     1000 CALL TPSCAL(SPDH,SWI,SWC,WSI,0LLTPS)
160 • 160.000     STOP
161 • 161.000     END
162 • 162.000     SUBROUTINE ARRFIL
163 • 163.000     COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
164 • 164.000     1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
165 • 165.000     2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
166 • 166.000     3,XVP(20),MFB(20),MAF(20)
167 • 167.000     NIP=NIF(11)
168 • 168.000     NIPL=NIP-1
169 • 169.000     NIPP=NIP+1
170 • 170.000     DO 5 I=NIPP,30
171 • 171.000     5  ZZ(I)=0.
172 • 172.000     IJK=1
173 • 173.000     DO 10 I=1,NIP
174 • 174.000     IF (ZZ(I).LE.0.) GO TO 10
175 • 175.000     IJK=I
176 • 176.000     GO TO 15
177 • 177.000     10  CONTINUE
178 • 178.000     15  IF (IJK.LE.2) GO TO 35
179 • 179.000     IJJ=IJK+1
180 • 180.000     VAL=FS(IJK,I1)+FS(I1,I1)
181 • 181.000     DO 30 I=2,IJJ

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```

182 • 182.000      VALL=FS(I,II)=FS(I,II)
183 • 183.000  30  ZZ(I)=ZZ(IJK)*VALL/VAL
184 • 184.000  35  IK=IJK+1
185 • 185.000  40  D8 50 I=IK,NIP
186 • 186.000      IF(ZZ(I).GT.0.) GO TO 50
187 • 187.000      IKK=I
188 • 188.000      GO TO 60
189 • 189.000  50  CONTINUE
190 • 190.000      RETURN
191 • 191.000  60  IKKP=IKK+1
192 • 192.000      IKKL=IKK-1
193 • 193.000      D8 70 J=IKKP,NIP
194 • 194.000      IF(ZZ(J).LE.0.) GO TO 70
195 • 195.000      JK=J
196 • 196.000      GO TO 75
197 • 197.000  70  CONTINUE
198 • 198.000      GO TO 80
199 • 199.000  75  DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(IJK,II)-FS(IKKL,II))
200 • 200.000      ZZ(IKK)=ZZ(IKKL)+DEL*(ZZ(IJK)-ZZ(IKKL))
201 • 201.000      IK=IKK+1
202 • 202.000      IF(IK.GE.NIP) RETURN
203 • 203.000      GO TO 40
204 • 204.000  80  VAL=FS(NIP,II)=FS(IKKL,II)
205 • 205.000      IF(VAL.EQ.0.) RETURN
206 • 206.000      D8 85 I=IKK,NIP
207 • 207.000      VALL=FS(NIP,II)=FS(I,II)
208 • 208.000  85  ZZ(I)=ZZ(IKK)*VALL/VAL
209 • 209.000      RETURN
210 • 210.000      END
211 • 211.000      SUBROUTINE REDEYE
212 • 212.000      COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
213 • 213.000      1,A(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
214 • 214.000      2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
215 • 215.000      3,XVP(20),MFB(20),MAF(20)
216 • 216.000      NIP=NIF(11)
217 • 217.000      LLL=-1
218 • 218.000      D8 15 I=1,NIP
219 • 219.000      IF(ICN(I,II).GT.0) GO TO 10
220 • 220.000      RED(I,II)=-1
221 • 221.000      GO TO 15
222 • 222.000  10  LLL=LLL+1
223 • 223.000      IKEEP2=1
224 • 224.000  15  CONTINUE
225 • 225.000      IF(LLL.LE.0) RETURN
226 • 226.000      D8 30 I=1,IKEEP2
227 • 227.000      IF(RED(I,II).LT.0.) GO TO 30
228 • 228.000      IKEEP1=1
229 • 229.000      GO TO 35
230 • 230.000  30  CONTINUE
231 • 231.000  35  IK=IKEEP1+1
232 • 232.000      IJ=IKEEP2+1
233 • 233.000  40  D8 50 I=IK,IJ
234 • 234.000      IF(RFU(I,II).GE.0.) GO TO 50
235 • 235.000      IKK=I
236 • 236.000      GO TO 60
237 • 237.000  50  CONTINUE
238 • 238.000      RETURN
239 • 239.000  60  IKKP=IKK+1
240 • 240.000      IKKL=IKK-1
241 • 241.000      D8 70 J=IKKP,IKEEP2
242 • 242.000      IF(RED(J,II).LT.0.) GO TO 70

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```

243 * 243.000      JK=J
244 * 244.000      GO TO 75
245 * 245.000      70  CONTINUE
246 * 246.000      75  DEL=(FS(IKK,II)-FS(IKKL,II))/(FS(JK,II)-FS(IKKL,II))
247 * 247.000      RED(IKK,II)=RED(IKKL,II)+DEL*(RED(JK,II)-RED(IKKL,II))
248 * 248.000      IK=IKK+1
249 * 249.000      IF(IK.LT.IKEEP2) GO TO 40
250 * 250.000      RETURN
251 * 251.000      END
252 * 252.000      SUBROUTINE CGENER
253 * 253.000      COMMON I,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
254 * 254.000      1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
255 * 255.000      2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
256 * 256.000      3,XVP(20),MFB(20),MAF(20)
257 * 257.000      ELK(X)=1/((-.2206*X)+.6455)*X+.146)*X+.9987
258 * 258.000      NIP=NIF(II)
259 * 259.000      DO 40 I=1,NIP
260 * 260.000      IF(ISH(I,II).LE.0.AND.ISH(I,II).GT.18) GO TO 40
261 * 261.000      IF(A(I,II).LE.0.) A(I,II)=.000001
262 * 262.000      IF(B(I,II).LE.0.) B(I,II)=.000001
263 * 263.000      ICIT=ISH(I,II)
264 * 264.000      GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38),ICTT
265 * 265.000      21  CV(I,II)=1.
266 * 266.000      CW(I,II)=2.
267 * 267.000      GO TO 40
268 * 268.000      22  CV(I,II)=.5
269 * 269.000      CW(I,II)=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
270 * 270.000      GO TO 40
271 * 271.000      23  CV(I,II)=.5
272 * 272.000      CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
273 * 273.000      CW(I,II)=(B(I,II)+CCW)/(A(I,II)+B(I,II))
274 * 274.000      GO TO 40
275 * 275.000      24  CV(I,II)=.785
276 * 276.000      X=B(I,II)/A(I,II)
277 * 277.000      IF(X.GT.1.) X=1./X
278 * 278.000      CW(I,II)=2.*ELK(X)/(X+1.)
279 * 279.000      GO TO 40
280 * 280.000      25  CV(I,II)=.785
281 * 281.000      XX=B(I,II)/A(I,II)
282 * 282.000      X=B(I,II)/(2.*A(I,II))
283 * 283.000      IF(X.GT.1.) X=1./X
284 * 284.000      CW(I,II)=(XX+ELK(X)*(XX+2.)/(X+1.))/(XX+1.)
285 * 285.000      GO TO 40
286 * 286.000      26  CV(I,II)=.785
287 * 287.000      XX=B(I,II)/A(I,II)
288 * 288.000      X=2.*B(I,II)/(3.*A(I,II))
289 * 289.000      IF(X.GT.1.) X=1./X
290 * 290.000      C1=ELK(X)*(XX+1.5)/(X+1.)
291 * 291.000      X=2.*B(I,II)/A(I,II)
292 * 292.000      IF(X.GT.1.) X=1./X
293 * 293.000      C2=ELK(X)*(XX+.5)/(X+1.)
294 * 294.000      CW(I,II)=(C1+C2)/(XX+1.)
295 * 295.000      GO TO 40
296 * 296.000      27  CV(I,II)=.987
297 * 297.000      X=B(I,II)/A(I,II)
298 * 298.000      IF(X.GT.1.) X=1./X
299 * 299.000      CW(I,II)=1.5+.5*ELK(X)/(X+1.)
300 * 300.000      GO TO 40
301 * 301.000      28  CV(I,II)=.946
302 * 302.000      X=B(I,II)/A(I,II)
303 * 303.000      IF(X.GT.1.) X=1./X

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304	•	304.000		CW(I,II)=1.+ELK(X)/(X+1.)
305	•	305.000		GO TO 40
306	•	306.000	29	CV(I,II)=.893
307	•	307.000		XX=B(I,II)/A(I,II)
308	•	308.000		X=2.+B(I,II)/A(I,II)
309	•	309.000		IF(X.GT.1.) X=1./X
310	•	310.000		CW(I,II)=(1.+2.*ELK(X)*(XX+.5)/(X+1.))/(XX+1.)
311	•	311.000		GO TO 40
312	•	312.000	30	CV(I,II)=.839
313	•	313.000		XX=B(I,II)/A(I,II)
314	•	314.000		X=4.+B(I,II)/(3.*A(I,II))
315	•	315.000		IF(X.GT.1.) X=1./X
316	•	316.000		CW(I,II)=(1.5+2.*ELK(X)*(XX+.75)/(X+1.))/(XX+1.)
317	•	317.000		GO TO 40
318	•	318.000	31	CV(I,II)=.866
319	•	319.000		X=B(I,II)/A(I,II)
320	•	320.000		IF(X.GT.1.) X=1./X
321	•	321.000		CW(I,II)=.5+1.5*ELK(X)/(X+1.)
322	•	322.000		GO TO 40
323	•	323.000	32	CV(I,II)=.726
324	•	324.000		CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
325	•	325.000		C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
326	•	326.000		X=B(I,II)/A(I,II)
327	•	327.000		IF(X.GT.1.) X=1./X
328	•	328.000		CW(I,II)=.5+C3*ELK(X)/(X+1.)
329	•	329.000		GO TO 40
330	•	330.000	33	CV(I,II)=.764
331	•	331.000		CCW=SQRT(4.*A(I,II)**2+B(I,II)**2)
332	•	332.000		C3=(B(I,II)+CCW)/(A(I,II)+B(I,II))
333	•	333.000		X=B(I,II)/A(I,II)
334	•	334.000		IF(X.GT.1.) X=1./X
335	•	335.000		CW(I,II)=C3/3.+4.*ELK(X)/(3.*X+3.)
336	•	336.000		GO TO 40
337	•	337.000	34	CV(I,II)=.675
338	•	338.000		C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
339	•	339.000		X=B(I,II)/A(I,II)
340	•	340.000		IF(X.GT.1.) X=1./X
341	•	341.000		CW(I,II)=.5+C2*ELK(X)/(X+1.)
342	•	342.000		GO TO 40
343	•	343.000	35	CV(I,II)=.719
344	•	344.000		C2=2.*SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
345	•	345.000		X=B(I,II)/A(I,II)
346	•	346.000		IF(X.GT.1.) X=1./X
347	•	347.000		CW(I,II)=C2/3.+4.*ELK(X)/(3.*X+3.)
348	•	348.000		GO TO 40
349	•	349.000	36	CV(I,II)=.785
350	•	350.000		X=B(I,II)/A(I,II)
351	•	351.000		IF(X.GT.1.) X=1./X
352	•	352.000		CW(I,II)=1.+ELK(X)/(X+1.)
353	•	353.000		GO TO 40
354	•	354.000	37	CV(I,II)=.946
355	•	355.000		X=B(I,II)/A(I,II)
356	•	356.000		IF(X.GT.1.) X=1./X
357	•	357.000		CW(I,II)=1.5+.5*ELK(X)/(X+1.)
358	•	358.000		GO TO 40
359	•	359.000	38	CV(I,II)=.5
360	•	360.000		CW(I,II)=1.+SQRT(A(I,II)**2+B(I,II)**2)/(A(I,II)+B(I,II))
361	•	361.000	40	CONTINUE
362	•	362.000		CALL CCFILL
363	•	363.000		RETURN
364	•	364.000		END

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```

365 • 365.000      SUBROUTINE CCFILL
366 • 366.000      COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
367 • 367.000      1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
368 • 368.000      2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
369 • 369.000      3,XVP(20),MFB(20),MAF(20)
370 • 370.000      NIP=NIF(11)
371 • 371.000      IJK=1
372 • 372.000      IF(CW(1,11).GT.0.) GO TO 40
373 • 373.000      DO 30 J=2,NIP
374 • 374.000      IJK=IJK+1
375 • 375.000      IF(CW(J,11).LT.0.) GO TO 30
376 • 376.000      IJ=IJK-1
377 • 377.000      DO 20 K=1,IJ
378 • 378.000      CW(K,11)=CW(IJK,11)
379 • 379.000      20 CV(K,11)=CV(IJK,11)
380 • 380.000      GO TO 40
381 • 381.000      30 CONTINUE
382 • 382.000      RETURN
383 • 383.000      40 IF(IJK.GE.NIP) RETURN
384 • 384.000      IK=IJK+1
385 • 385.000      IF(CW(IK,11).LE.0.) GO TO 60
386 • 386.000      IJK=IK+1
387 • 387.000      GO TO 40
388 • 388.000      60 IF(IK.GE.NIP) GO TO 90
389 • 389.000      IKP=IK+1
390 • 390.000      DO 80 L=IKP,NIP
391 • 391.000      IF(CW(L,11).LE.0.) GO TO 80
392 • 392.000      IJJ=L
393 • 393.000      GO TO 110
394 • 394.000      80 CONTINUE
395 • 395.000      90 DO 100 K=IK,NIP
396 • 396.000      CV(K,11)=CV(IJK,11)
397 • 397.000      100 CW(K,11)=CW(IJK,11)
398 • 398.000      RETURN
399 • 399.000      110 NE=IJJ-IK
400 • 400.000      NB=IK-1
401 • 401.000      FP=A(IJK,11)+B(IJK,11)
402 • 402.000      RP=A(IJJ,11)+B(IJJ,11)
403 • 403.000      FM=A(IJK,11)*B(IJK,11)
404 • 404.000      RM=A(IJJ,11)*B(IJJ,11)
405 • 405.000      DELCV=CV(IJK,11)-CV(IJJ,11)
406 • 406.000      DO 145 K=1,NF
407 • 407.000      KK=NB+K
408 • 408.000      XBL=(FS(KK,11)-FS(IJK,11))/(FS(IJJ,11)-FS(IJK,11))
409 • 409.000      XBLM=1.-XBL
410 • 410.000      AX=A(IJK,11)+XBL*(A(IJJ,11)-A(IJK,11))
411 • 411.000      BX=B(IJK,11)+XBL*(B(IJJ,11)-B(IJK,11))
412 • 412.000      CW(KK,11)=(CW(IJK,11)*FP+XBLM*CW(IJJ,11)+RP*XBL)/(AX+BX)
413 • 413.000      ABX=AX+BX
414 • 414.000      IF(DELCV) 120,130,140
415 • 415.000      120 CV(KK,11)=CV(IJJ,11)+XBLM**2*DELCV*FM/ABX
416 • 416.000      GO TO 145
417 • 417.000      130 CV(KK,11)=CV(IJK,11)
418 • 418.000      GO TO 145
419 • 419.000      140 CV(KK,11)=CV(IJK,11)+XBL**2*DELCV*RM/ABX
420 • 420.000      145 CONTINUE
421 • 421.000      IJK=IJJ
422 • 422.000      GO TO 40
423 • 423.000      RETURN
424 • 424.000      END
425 • 425.000      SUBROUTINE P8DM8D

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426	426.000	COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
427	427.000	1,B(30,20),ISH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
428	428.000	2,CW(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
429	429.000	3,XVP(20),MFB(20),MAF(20)
430	430.000	NIP=NIF(I1)
431	431.000	NIPL=NIP-1
432	432.000	XM=NMP(I1)
433	433.000	AAP=0.
434	434.000	XAP=0.
435	435.000	DO 20 I=1,NIPL
436	436.000	DAX=FS(I+1,I1)*FS(I,I1)
437	437.000	VL1=A(I,I1)*B(I,I1)
438	438.000	VL2=A(I,I1)*B(I+1,I1)
439	439.000	VL3=A(I+1,I1)*B(I,I1)
440	440.000	VL4=A(I+1,I1)*B(I+1,I1)
441	441.000	IF(CV(I,I1).GE.CV(I+1,I1)) GO TO 10
442	442.000	VLL=DAX*(CV(I+1,I1)*(VL2+VL3+2.*VL4)+2.*CV(I,I1)*VL1)/6.
443	443.000	XVV=DAX**2*(CV(I+1,I1)*(VL2+VL3+3.*VL4)+CV(I,I1)*VL1)/12.
444	444.000	GO TO 15
445	445.000	10 VLL=DAX*(CV(I,I1)*(2.*VL1+VL2+VL3)+2.*CV(I+1,I1)*VL4)/6.
446	446.000	XVV=DAX**2*(CV(I,I1)*(VL1+VL2+VL3)+3.*CV(I+1,I1)*VL4)/12.
447	447.000	15 VLP(I1)=VLP(I1)+VLL
448	448.000	20 XVP(I1)=XVP(I1)+XVV+VLL*FS(I,I1)
449	449.000	VLP(I1)=XM*VLP(I1)
450	450.000	XVP(I1)=XM*XVP(I1)
451	451.000	IF(NMP(I1).LE.0) RETURN
452	452.000	DO 45 I=1,NIPL
453	453.000	DAX=FS(I+1,I1)*FS(I,I1)
454	454.000	P1=CW(I,I1)*(A(I,I1)+B(I,I1))
455	455.000	P2=CW(I+1,I1)*(A(I+1,I1)+B(I+1,I1))
456	456.000	WPX=DAX*(P1+P2)/2.
457	457.000	XPP=DAX**2*(P1+2.*P2)/6.
458	458.000	ARFAF=CV(I,I1)*A(I,I1)*B(I,I1)
459	459.000	AREAA=CV(I+1,I1)*A(I+1,I1)*B(I+1,I1)
460	460.000	WPY=AREAF+ARFAA
461	461.000	WPP=SQRT(WPX**2+WPY**2)
462	462.000	WAP(I1)=WAP(I1)+WPP
463	463.000	XWP(I1)=XWP(I1)+XPP+WPP/WPX+WPP*FS(I,I1)
464	464.000	IF(RED(I,I1).LT.0.) GO TO 45
465	465.000	35 IF(RED(I+1,I1).LT.0.) GO TO 45
466	466.000	AAP=DAX*(RED(I,I1)+RED(I+1,I1))/2.
467	467.000	XAP=DAX**2*(RED(I,I1)/6.+RED(I+1,I1)/3.)
468	468.000	WAP(I1)=WAP(I1)+AAP
469	469.000	XWP(I1)=XWP(I1)+XAP+AAP*FS(I,I1)
470	470.000	45 CONTINUE
471	471.000	ENDS=0.
472	472.000	ENDMUL=0.
473	473.000	IF(MFB(I1)) 55,60,50
474	474.000	50 ENDS=CV(I,I1)*A(I,I1)*B(I,I1)
475	475.000	ENDMUL=ENDS*FS(I,I1)
476	476.000	GO TO 60
477	477.000	55 ENDS=CV(I,I1)*A(I,I1)*B(I,I1)
478	478.000	ENDMUL=ENDS*FS(I,I1)
479	479.000	60 YET=CV(NIP,I1)*A(NIP,I1)*B(NIP,I1)
480	480.000	IF(MAF(I1)) 75,80,70
481	481.000	70 ENDS=ENDS+YET
482	482.000	ENDMUL=ENDMUL+YET*FS(NIP,I1)
483	483.000	GO TO 80
484	484.000	75 ENDS=ENDS+YET
485	485.000	ENDMUL=ENDMUL+YET*FS(NIP,I1)
486	486.000	80 WAP(I1)=XM*(WAP(I1)+ENDS)

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TABLE 3.3-16  
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```

487 * 487.000      XWP(11),XM*(XWP(11)+ENDMUL)
488 * 488.000      RETURN
489 * 489.000      END
490 * 490.000      SUBROUTINE TPSCAL(SPDM,SWI,SWC,WS1,OLLTPS)
491 * 491.000      COMMON I1,NPD,NAMEPD(10,20),NAMEFL(20),FS(30,20),A(30,20)
492 * 492.000      1,Z(30,20),TSH(30,20),ZZ(30),RED(30,20),ICN(30,20),CV(30,20)
493 * 493.000      2,CN(30,20),NMP(20),NIF(20),NGP(20),WAP(20),VLP(20),XWP(20)
494 * 494.000      3,XVP(20),MFB(20),MAF(20)
495 * 495.000      COMMON I11/TITLS,BASA,BASEWT,TPSCON,BTPSWT,WGTPSA
496 * 496.000      1,WGWT,WGLEA,WGLEWT,TWGWT,TPPSA,TWT,TLEA,TLEWT
497 * 497.000      2,TTWT,MCSA,MCSTPS,TOTTPS,IBTWT,LDWT,PRGWT,PPC
498 * 498.000      3,MYC,SCWT
499 * 499.000      4,DIMENSION TITLE(20)
500 * 500.000      5,INTEGER SPDM
501 * 501.000      IF(SPDM,EQ,0) GO TO 25
502 * 502.000      READ(5,40) TITLE
503 * 503.000      READ(5,70) NCTPS,NCA,FWDTPS,FWDA,CTTPS,CTA,CSTPS
504 * 504.000      READ(5,70) CSA,CBTPS,CBA,ATTPS,ATA,ASTPS,ASA
505 * 505.000      READ(5,70) ABTPS,ABA,BASTPS,BASA,TPSCON,WGTPS,WGA
506 * 506.000      READ(5,70) WGPLE,WLETPS,TLTPS,TLA,TLPLE,TLETPS,MCSTPS
507 * 507.000      READ(5,70) MCSA,WACON,TACON,IRA,IBTPS,IBC,LDA
508 * 508.000      READ(5,70) LDTPS,PRBA,PROTPS,PROC,PPC,MYC,SCA
509 * 509.000      READ(5,80) SCTPS
510 * 510.000      C W/S CORRECTION
511 * 511.000      BLANWT=OLLTPS+TOTTPS
512 * 512.000      WSC=BLANWT/(SWI+SWC)
513 * 513.000      5 TLANWT=BLANWT
514 * 514.000      DUWT=(WSC/WS1)**.125
515 * 515.000      C BODY TPS WEIGHT
516 * 516.000      NCWT=NCTPS*NCA*DUWT
517 * 517.000      FWDWT=FWDTPS*FWDA*DUWT
518 * 518.000      CTWT=CTTPS*CTA*DUWT
519 * 519.000      CSWT=CSTPS*CSA*DUWT
520 * 520.000      CBWT=CBTPS*CBA*DUWT
521 * 521.000      CTOTA=CTA+CSA+CBA
522 * 522.000      CTOTWT=CTWT+CSWT+CBWT
523 * 523.000      ATWT=ATTPS*ATA*DUWT
524 * 524.000      ASWT=ASTPS*ASA*DUWT
525 * 525.000      ABWT=ABTPS*ABA*DUWT
526 * 526.000      ATOTA=ATA+ASA+ABA
527 * 527.000      ATOTWT=ATWT+ASWT+ABWT
528 * 528.000      BASEWT=RASTPS*BASA*DUWT
529 * 529.000      IBTWT=IBA*IBTPS+IBC
530 * 530.000      BTPSWT=NCWT+FWDWT+CTOTWT+ATOTWT+BASEWT+TPSCON+IBTWT
531 * 531.000      C WING TPS WEIGHT
532 * 532.000      WGA=WGA**ACON
533 * 533.000      WGLEA=WGA*WGPLE
534 * 534.000      WGTPSA=WGA*WGLEA
535 * 535.000      WGWT=WGTPSA*WGTPS*DUWT
536 * 536.000      WGLEWT=WGLEA*WLETPS*DUWT
537 * 537.000      TWGWT=WGWT+WGLEWT
538 * 538.000      C TAIL TPS WEIGHT
539 * 539.000      TWA=TLA*TACON
540 * 540.000      TLEA=TWA*TLPLE
541 * 541.000      TTPSA=TWA*TLEA
542 * 542.000      TWT=TTPSA*TLTPS*DUWT
543 * 543.000      TLEWT=TLEA*TLETPS*DUWT
544 * 544.000      TTWT=TWT+TLEWT
545 * 545.000      MCSWT=MCSTPS*MCSA*DUWT
546 * 546.000      LDWT=LDTPS*LDTPS
547 * 547.000      PRGWT=PRBA*PROTPS+PROC

```



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TABLE 3.3-16  
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```

548 • 548.000      SCWT=SCA+SCTPS
549 • 549.000      T8TPS=8TPSWT+TWGWT+TTWT+MCSWT
550 • 550.000      1*LDWT+PR8WT+PPC+HYC+SCWT
551 • 551.000      8LANWT=8LLTPS+T8TPS
552 • 552.000      WSC=8LANWT/(SW)+SWC)
553 • 553.000      IF(ABS(TLANWT-8LANWT).LE.1.) GO TO 30
554 • 554.000      GO TO 5
555 • 555.000      25 IF(SPUM.GT.C) GO TO 30
556 • 556.000      WRITE(6,100)
557 • 557.000      WRITE(6,200)
558 • 558.000      WRITE(6,800) T8TL5,BASA,BASEWT,8BTWT,TPSC8N,8TPSWT
559 • 559.000      GO TO 40
560 • 560.000      30 WRITE(6,900) TITLE
561 • 561.000      WRITE(6,100)
562 • 562.000      WRITE(6,200)
563 • 563.000      WRITE(6,300) NCA,NCWT,FWDA,FWDWT,CT8TA,CT8TWT
564 • 564.000      1,AT8TA,AT8TWT,BASA,BASEWT,8BTWT,TPSC8N,8TPSWT
565 • 565.000      40 WRITE(6,400) WGTPSA,WGWT,WGLEFA,WGLEWT,TWGWT
566 • 566.000      WRITE(6,500) TTPSA,TWT,TLEA,TLEWT,TTWT
567 • 567.000      WRITE(6,600) MCSA,MCSTPS
568 • 568.000      WRITE(6,650) LDWT,PR8WT,PPC,HYC,SCWT
569 • 569.000      WRITE(6,700) T8TPS
570 • 570.000      70 FORMAT(7F10.0)
571 • 571.000      80 FORMAT(1F10.0)
572 • 572.000      90 FORMAT(20A2)
573 • 573.000      100 FORMAT(//,35X,TPS WEIGHT SUMMARY!)
574 • 574.000      200 FORMAT(//,29X,1ITEM!,10X,1AREA!,10X,1WEIGHT!)
575 • 575.000      300 FORMAT(//,26X,1BASE CONE!,5X,F10.0,5X,F10.0,/,26X,
576 • 576.000      11FWD SECT!,5X,F10.0,5X,F10.0,/,26X,1CT SECT!,
577 • 577.000      25X,F10.0,5X,F10.0,/,26X,1AFT SECT!,5X,F10.0,5X,
578 • 578.000      3F10.0,/,26X,1BASE!,10X,F10.0,5X,F10.0,/,26X,
579 • 579.000      41BBDY INT, TPS!,16X,F10.0,/,26X,1CONSTANT!,21X,F10.0
580 • 580.000      5,/,26X,1TOTAL BBDY!,19X,F10.0)
581 • 581.000      400 FORMAT(//,26X,1WING!,10X,F10.0,5X,F10.0,/,26X,
582 • 582.000      11WING LE!,6X,F10.0,5X,F10.0,/,26X,1TOTAL WING!,19X,F10.0)
583 • 583.000      500 FORMAT(//,26X,1TAIL!,10X,F10.0,5X,F10.0,/,26X,
584 • 584.000      11TAIL LE!,6X,F10.0,5X,F10.0,/,26X,1TOTAL TAIL!,19X,F10.0)
585 • 585.000      600 FORMAT(//,26X,1MIS C. S!,4X,F10.0,5X,F10.0)
586 • 586.000      650 FORMAT(//,26X,1LAND+DBCK TPS!,15X,F10.0,/,26X,
587 • 587.000      11PROP: TPS!,20X,F10.0,/,26X,1PRIME PWR TPS!,16X,F10.0
588 • 588.000      2,/,26X,1HYDRAULIC TPS!,16X,F10.0,/,26X,1SURF. CNT, TPS!
589 • 589.000      3,14X,F10.0)
590 • 590.000      700 FORMAT(//,26X,1TOTAL TPS!,20X,F10.0//)
591 • 591.000      800 FORMAT(//,26X,1BBDY-BASE!,20X,F10.0,/,26X,1BASE!,10X,F10.0,
592 • 592.000      15X,F10.0,/,26X,1BBDY INT, TPS!,16X,F10.0,/,26X,1CONSTANT!
593 • 593.000      2,21X,F10.0,/,26X,1TOTAL BBDY!,19X,F10.0)
594 • 594.000      900 FORMAT(//,29X,20A2)
595 • 595.000      RETURN
596 • 596.000      END

```



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3.4 Landing and Docking Model - The Landing and Docking Model includes the main and nose landing gear, deceleration chutes, interstage separation systems, and cargo handling gear.

3.4.1 Landing Gear - The main landing gear configuration used in the development of weight equations for the shock strut cylinder and piston is shown in Figure 3.4-1. The dimension  $L_5$  locates the inboard and outboard wheel reactions for either two or four tires. The axle transmits the wheel loads to the piston which transmits its load through sliding bearings to the cylinder. The cylinder transmits its load to the side brace link and to the fuselage attach points. All the ground drag load is carried to the aft fuselage attach fitting.

The critical sections for the cylindrical members are designed primarily by bending. It can be assumed that these members fail through exceeding an allowable modulus of rupture in bending ( $F_b$ ). The value of  $F_b$  depends on  $d/t$ . Figure 3.4-2 presents curves from MIL-HDBK-5B for low-alloy-steel tubing. An expression for cross sectional area was derived as follows:

$$F_b = \frac{M}{S}$$

where  $F_b$  is the bending stress,  $M$  is the bending moment, and  $S$  is the section modulus

$$S = \frac{M}{R_b C_1 F_{tu}}$$

where  $R_b = \frac{F_b}{F_b}$ ,  $C_1 = \frac{F_b}{F_{tu}}$ , and  $F_{tu}$  is ultimate tensile strength.

Even though bending is the overwhelming design condition, an allowance for other stresses can be made by using a value of  $R_b$  equal to one.

$$S = \frac{\pi(R^4 - r^4)}{4R} ; \quad r = \frac{d/t - 2}{d/t} \quad R = K, R$$

where  $R$  is the outside radius,  $r$  is the inside radius,  $d$  the outside diameter, and  $t$  the tube thickness.

$$R = \left[ \frac{4S}{\pi(1 - K_1^4)} \right]^{1/3}$$

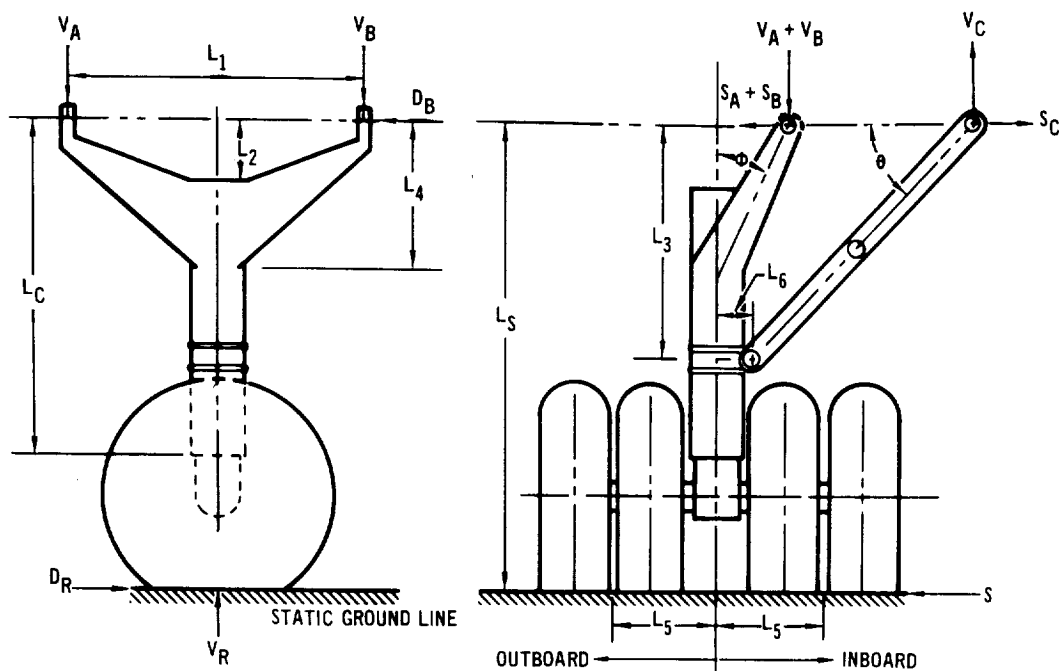


FIGURE 3.4-1 MAIN LANDING GEAR

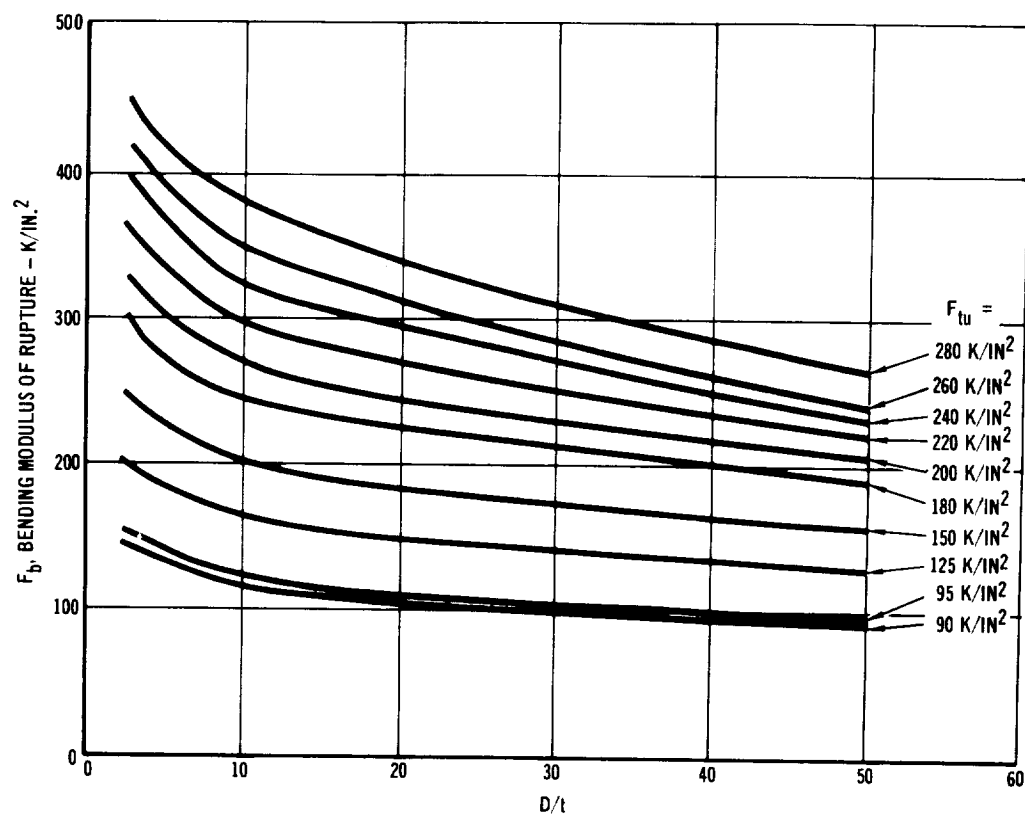


FIGURE 3.4-2 BENDING MODULUS OF RUPTURE FOR ROUND LOW-ALLOY-STEEL TUBING

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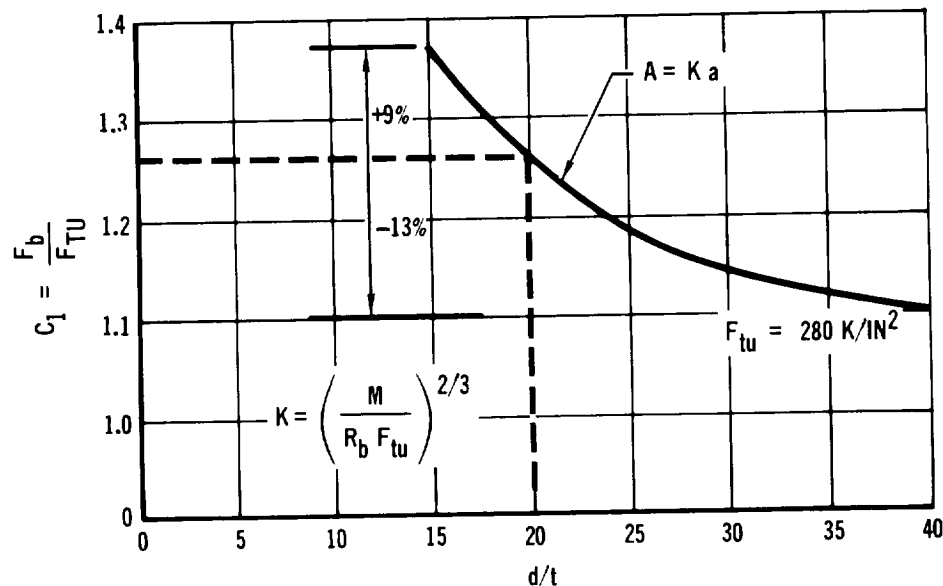
For the cross-sectional area of a tube is

$$A = \pi(R^2 - r^2) = \pi R^2(1 - K_1^2)$$

The required cross-sectional area for a tube in bending becomes

$$A = \underbrace{\left(\frac{M}{R_b F_{tu}}\right)^{2/3}}_{\text{Not dependent on } d/t \text{ and input for each case.}} \underbrace{\left[\frac{4}{\pi C_1 (1 - K_1^2)^4}\right]^{2/3} (1 - K_1^2) \pi}_{\text{Dependent on } d/t \text{ or constant.}}$$

It was determined that a reasonable range of  $d/t$  values for landing gear would be 15 to 30. The variation in area to  $d/t$  is shown below:



Using  $d/t = 20$ , areas will vary less than 10 percent in the range of  $d/t$ 's required. For this  $d/t$ , a value for

$$C_1 = \frac{F_b}{F_{tu}}$$

of 1.21 yields only a 2.5 percent variation in area for all the  $F_{tu}$  values in Figure 3.4-2. The required cross-sectional area reduces to

$$A = 1.26 \left(\frac{M}{R_b F_{tu}}\right)^{2/3}$$

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Shock Strut Cylinder Weight Equation - Figure 3.4-1 presents the loading diagram and gear geometry.

Cylinder Tube - The critical tube cross section is at A.A, and loading is based on braked roll with 20 percent imbalance between inboard reaction ( $V_I$ ) and outboard reaction ( $V_O$ ) (i.e., 40-60 percent distribution of load). Ultimate loads are:

$$D_R = 0.4 W_G (1.4) \text{ and } V_R = 0.5 W_G (1.4)$$

where  $W_G$  = greater of the maximum design gross weight or 1.2 times landing design weight

$$V_O = 0.6 V_R ; \quad V_I = 0.4 V_R$$

$$V_C = \frac{1}{L_7} \left[ V_O(L_5 + L_8) - V_I(L_5 - L_8) \right]$$

$$S_C = V_C / \tan \theta$$

$$V_A + V_B = V_R + V_C$$

$$V_A = \frac{1}{L_1} \left[ L_5 D_R - (V_R + V_C) \frac{L_1}{2} \right]$$

$$V_B = V_R + V_C + V_A$$

$$M_{A-A} = 0.5 L_1 (V_A + V_B) - L_4 D_R$$

The area of the cylinder is

$$A_C = 1.26 \left( \frac{M_{A-A}}{.85 F_{tu}} \right)^{2/3} ; \quad \text{radius of cylinder} = R_C \sqrt{\frac{A_C}{.19}}$$

and its weight

$$W_C = A_C (L_C - L_2) 0.283$$

Cylinder Pivot Arms (Drag Brace)

Forward Pivot - The critical cross section is at A-A (where arm attaches to cylinder), and loading is based on reverse brake roll (i.e.,  $V_A$  has same value as  $V_B$  for a brake roll).

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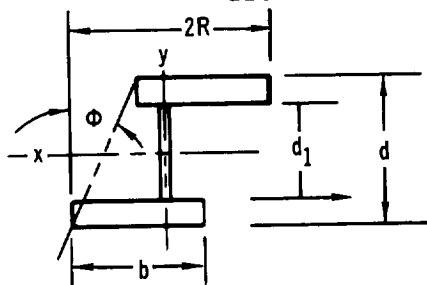
$$\text{Axial Load} = P_A = (V_B \cos \phi + S_C \sin \phi) \sin \beta$$

$$\text{where } \tan \beta = \frac{L_2 + L_4}{L_1}$$

$$\text{Length of pivot arm} = L_A = (.5 L_1 - R_C) / \cos \beta \cos \phi$$

$$M_{\text{side}} = (V_B \cos \phi + S_C \sin \phi) \cos (L_A)$$

$$M_{\text{front}} = (V_B \sin \phi - S_C \cos \phi) L_A$$



$$S_X = \frac{b (d^3 - d_1^3)}{6d} ; d = 9; b = 2R_C - 9 \sin \phi$$

$$S_X = \frac{(2 R_C - 10 \sin \phi)(.729 - d_1^3)}{54}$$

$$\text{allowable compressive stress} = F_C = F_{tu}$$

$$S_X = \frac{M_{\text{side}}}{F_C} ; d_1^3 = 729 - \frac{54 M_{\text{side}}}{F_C (2R_C - 9 \sin \phi)}$$

$$S_y \approx \frac{d_1 (2R_C)^2}{6} = \frac{M_{\text{front}}}{F_C} ; d_4 = \frac{6 M_{\text{front}}}{4 R_C^2 F_C}$$

$$\text{area of forward pivot} = A_F = \left[ d - (d_1 - d_4) b + \underbrace{(d_1 - d_4) l}_{\text{Web}} \right]$$

It is assumed that the web provides enough area for the axial load.  
The weight of the forward pivot arm is

$$W_{FA} = 1.05 A_F L_A (.283)(.5)$$

Aft Pivot - Axial load and  $M_{\text{side}}$  change from Fwd pivot values for a braked roll.

$$M_{\text{side}} = \left[ (V_B \cos \phi + S_C \sin \phi) \cos \beta - D_R \sin \beta \right] L_A$$

$$d_1'^3 = 729 - \frac{54 M'_{\text{side}}}{F_C (2R - 9 \sin \phi)}$$

$$\text{area of aft pivot} = A_A = \left[ d - (d'_1 - d_4) b + \underbrace{(d'_1 - d_4) l}_{\text{Web}} \right]$$

The weight of the aft pivot arm is

$$W_{AA} = 1.05 A_A L_A (.283)(.5)$$

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Shock Strut Cylinder Weight -

$$W_{SC} = W_C + W_{FA} + W_{AA}$$

Shock Strut Piston Weight Equation - The critical tube cross section is at the lower bearing for a braked roll. The moment at this point is

$$M_P = D_R (L_S - L_C)$$

The area of the piston is

$$A_P = 1.26 \frac{M_P^{2/3}}{F_{tu}}$$

and its weight

$$W_P = 1.5 A_P L_C (.283)$$

where 1.5 is a factor which includes bearings and lug end.

The brace weight was taken to be

$$BRACE = 0.1 * WC$$

where BRACE = weight of the brace (lb)

WC = weight of the shock strut cylinder (lb)

Brakes - The standard kinetic energy relationship for heat sink material versus energy was used for the brake system on the main gear. The aircraft in the correlations used steel as the heat sink, and the brake weight was kinetic energy/200,000, where 200,000 is the coefficient. Carbon brakes, as used in the Orbiter, require a modification in the coefficient. The steel brakes have an equivalent stack or amount of heat sink equal to 1.0, and an amount of associated material equal to 50 percent of the stack, or a total efficiency factor of 1.5. Carbon brakes have a stack of one, but there is an associated material increase to 90 percent, or an efficiency factor of 1.9. Combining the relative efficiencies of the two materials and the theoretical carbon heat sink capability of 400,000, the brake weight becomes

kinetic energy/315,000.

Tires and Tubes - From tire data in Reference J, a relationship between static load, and tire and tube weight was determined. A plot of this data is



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shown in Figure 3.4-3. The relationship was determined to be:

$$TWTT = SL * .006875$$

where TWTT is the weight of tires and tubes (lb), and SL is the static load (lb).

Attach Fittings - A relationship between weight of the shock strut cylinder and the attach fittings was found in Reference Q. The relationship was found to be:

$$ATF = 0.06 (TWSSC)^{1.1}$$

where: ATF is the weight of the attach fittings (lb), and TWSSC is the total weight of the shock strut cylinder (lb).

Wheels - From wheel data in Reference J, a relationship between static load and wheel weight was obtained. A plot of these data appears in Figure 3.4-4. The relationship was determined to be:

$$TWH = SL/266.6667$$

where: TWH is the wheel weight (lb), and SL is the static load (lb).

Axles - From a sample of commercial aircraft, a relationship between wheel weight and axle weight was determined. That relationship was found to be:

$$AXLES = TWH * 0.4426$$

where: AXLES is the axle weight (lb), and TWH is the wheel weight (lb).

Controls - The weight of the controls was obtained using an equation found in Reference Q. This equation is

$$Controls = 0.225 (WT)^{0.95}$$

where: Controls is the weight of the controls (lb), and WT is the total other weight of gear (lb).

Nose Gear - For the nose gear, a similar approach was taken to determine wheel, tire and tube, axle, and attach fitting weights as was used on the main gear.

The structural weight was assumed to be a percentage of the main-gear structural weight.

The control weight was determined through the use of the equation

$$Contn = (WTNG)^{0.95} * 0.85$$

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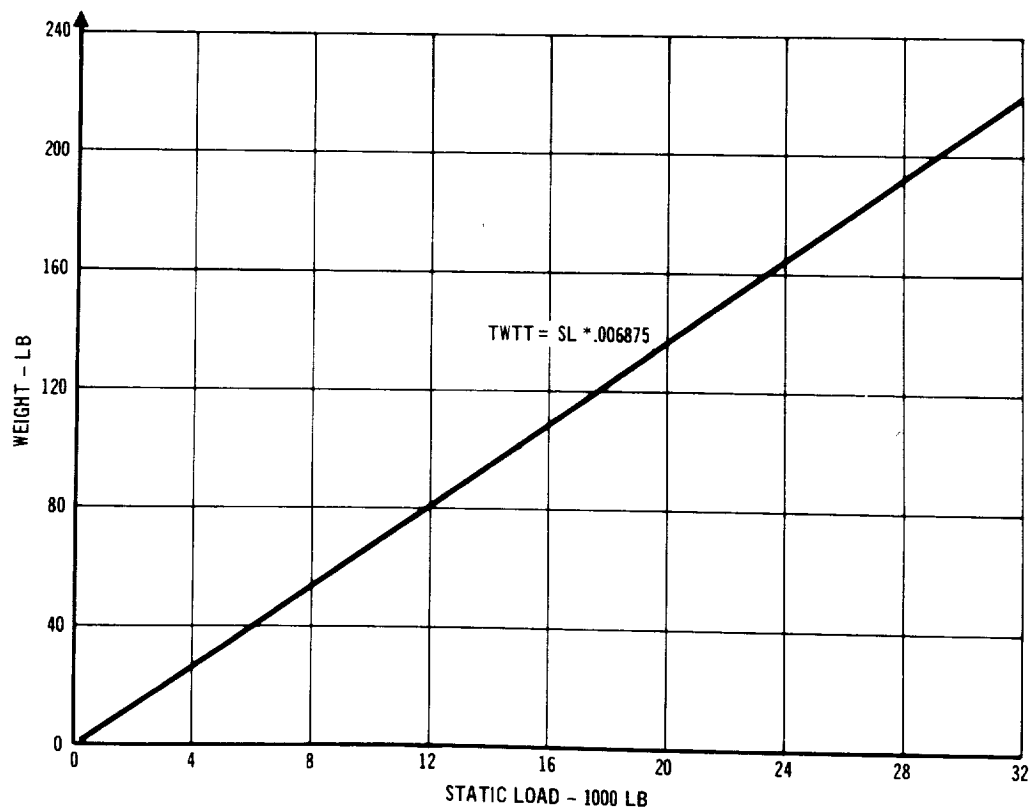


FIGURE 3.4-3 TIRE WEIGHT

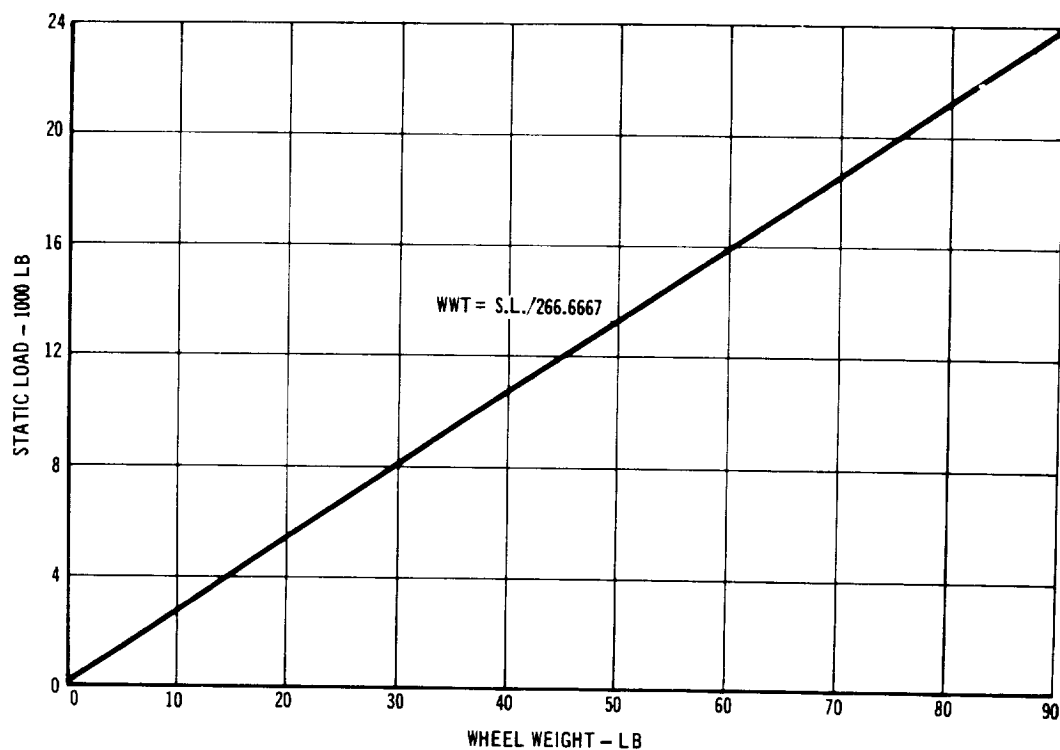


FIGURE 3.4-4 WHEEL WEIGHT

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where: Contn is the control weight for nose gear (lb), and WTNG is the total other weight for nose gear (lb).

3.4.2 Deceleration Chute - The deceleration chute weight is determined from data used during the Shuttle Phase B effort, and is essentially an analytical correlation of the Mercury and Gemini systems. The following are the theoretical relationships:

$$\text{Drag Chute} \quad \gamma_g = \gamma_{CP} + \gamma_R + \gamma_{CONT} + \gamma_{ATT} + \gamma_{CIRC}$$

Chute Pressure

$$Q = \frac{.07528}{2g} (1.6878 \text{ VTD})^2$$

Number of Risers

$$n = \frac{Do\pi}{2.5}$$

Riser Breaking Strength

$$S = \frac{\pi}{4n} C_D (Do)^2 Q(2.3)$$

Riser Unit Weight

$$\left(\frac{W}{L}\right)_R = .007 \left(\frac{S}{1000}\right)^{.91}$$

$$\gamma_{CP} \text{ (Canopy)} = .0074 (QC_D)^{.57} (Do^2 + 3Do)$$

$$\gamma_R \text{ (Risers)} = n Do \left(\frac{W}{L}\right)_R$$

$$\gamma_{CONT} \text{ (Container)} = .12^2 (\gamma_{CP})$$

$$\gamma_{ATT} \text{ (Att Ftng)} = .2 (\gamma_{CP})$$

$$\gamma_{CIRC} - \text{Estimated}$$

$$\gamma_{EJECTION} - \text{Estimated}$$

NOTE: Pilot chute weight calculated using same equations as drag chute.

where: Do is the effective chute diameter (ft),  $C_D$  is the chute drag coefficient, and VTD is the touchdown velocity (knots).

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These equations are combined in ESPER as the simple relationship:

$$\begin{aligned} \text{CHUTE} = & 1.5 * [1.82 * (0.0074 * (.07528 / (2.*32.2) \\ & \& * (1.6878 * \text{VTD}) **2) **.57 *(D*D \\ & \& +3.*D) + 10.)] \end{aligned}$$

where the estimated chute diameter and the touchdown speed are the inputs.

3.4.3 Payload Handling System and Interstage Separation - The payload handling system (manipulator, etc.) is a user controlled device and is considered a user input. The interstage separation mechanism is not configuration dependent, and as a relatively complex device, does not lend itself to a simplified weight estimation relationship, and is also considered a user input.

3.4.4 Model Accuracy - The landing gear model was checked for accuracy by comparing it with the actual weight of several aircraft of comparable landing weight and size. The following results were attained:

Aircraft	Actual Weight (lb)	Model Weight (lb)
DC-9	2784	2503
DC-7	4028	4169
DC-8	8988	7586
C-124	9162	5612
C-133	8275	8463
NR-Orbiter	7994	8827

This comparison indicates that the model predicts the weight of the four airplanes an average of 15 percent lower than the actual, while predicting the NR Orbiter 10 percent higher. This variation on the Orbiter could be caused by a reduction in design service life as compared to commercial type gear.

Table 3.4-1 is a list of input data, representing the NR Orbiter test run on the landing gear model. The dimensional data is schematically represented in Figure 3.4-5.

The model in ESPER has a greatly reduced input, listed with only the strut length, material, landing speed, wheel quantity, and brake type being required.

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TABLE 3.4-1  
INPUT DATA LIST

$L_1 = 94.92$  (IN)       $L_2 = 18.98$  (IN)       $L_3 = 58.46$  (IN)  
 $L_4 = 47.46$  (IN)       $L_5 = 25.50$  (IN)       $L_6 = 9.00$  (IN)

$LS = 116.93$  (IN)  
 $FTU = 280000.$  (PSI) - material allowable  
 $\Phi = .00$  (DEG)  
 $WL = 215115.$  (LB) - design landing weight  
 $NUMNT = 2.0$  - number of nose gear wheels  
 $NGR = 79000.$  (LB) - nose gear reaction  
 $WG = 215115.$  (LB) - design gross weight  
 $\Theta = 45.00$  (DEG)  
 $VSTALL = 150.0$  (KNTS) - design landing speed  
 $NUMW = 4.0$  - number of main gear wheels  
 $MGR = 235000.$  (LB) - main gear reaction  
 $IBTY = 1$  - brake/type if 0 is steel brakes  
if 1 is carbon brakes

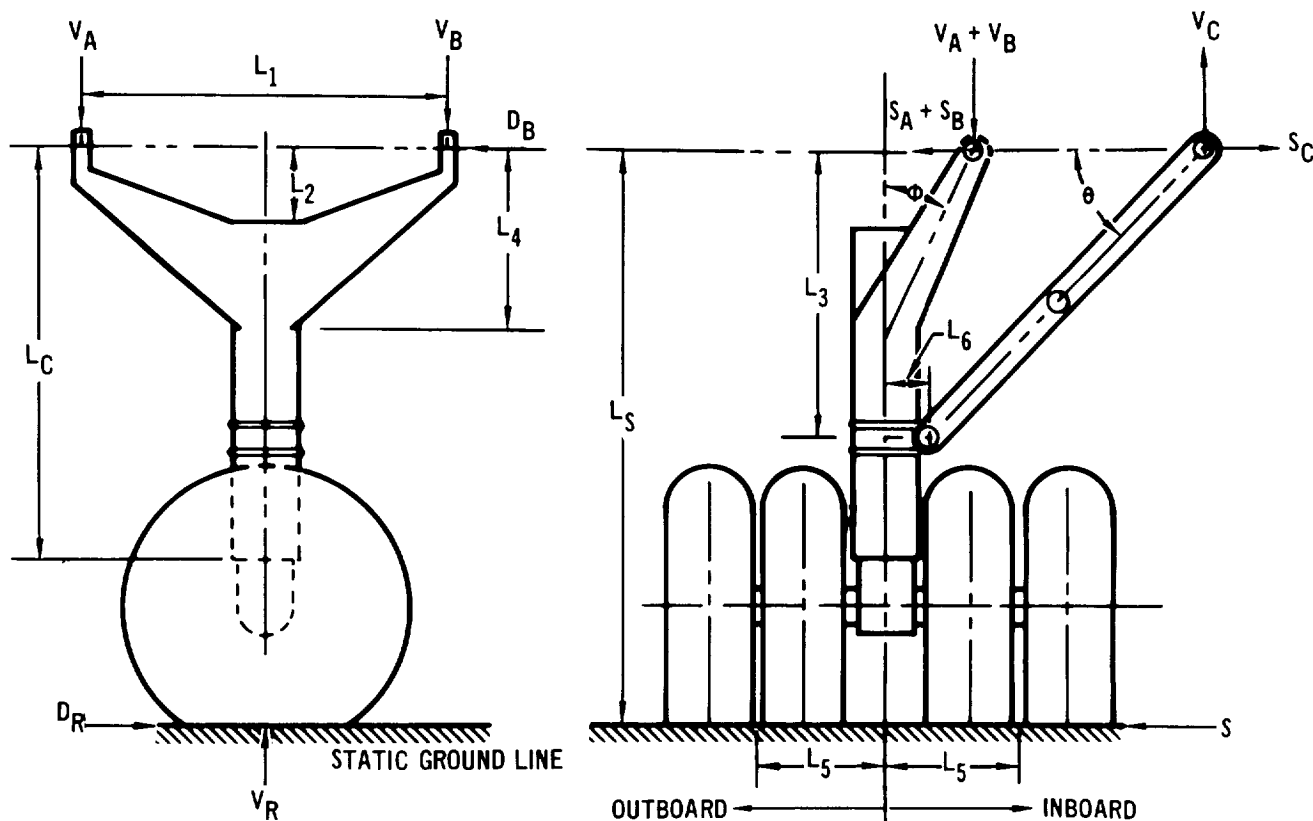


FIGURE 3.4-5 MAIN LANDING GEAR

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Table 3.4-2 is the test case output for the NR Orbiter. It should be noted that the main gear weight is for one side only. This is followed by a detailed listing of the model (Table 3.4-3).

TABLE 3.4-2  
MAIN GEAR WEIGHT

MAIN GEAR WEIGHT

CYLINDER	=	363.24 LBS
FORWARD PIVOT ARM	=	150.13 LBS
AFT PIVOT ARM	=	120.84 LBS
BRACE	=	36.32 LBS
TOTAL SHOCK STRUT CYLINDER	=	670.54 LBS
BRAKES	=	424.79 LBS
TIRES AND TUBES	=	1009.77 LBS
WHEELS	=	550.78 LBS
AXLES	=	243.59 LBS
ATTACH FITTINGS	=	75.43 LBS
CONTROLS	=	494.81 LBS
SHOCK STRUT PISTON	=	283.96 LBS
TOTAL	=	3753.67 LBS

NOSE GEAR WEIGHT

TIRES AND TUBES	=	434.50 LBS
WHEELS	=	118.50 LBS
AXLES	=	52.41 LBS
STRUCTURE	=	171.66 LBS
ATTACH FITTINGS	=	48.27 LBS
CONTROLS	=	495.88 LBS
TOTAL	=	1321.21 LBS

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TABLE 3.4-3  
PROGRAM LISTING

```

1.000 REAL LA,LS,LC,L1,L2,L4,L5,L7,L8,MAA,L3,L6
2.000 REAL MSIDE,MFRONT,MSIDEP,MP,NUMW,MGR,NGR,NUMNT
3.000 INTEGER ADD,YES/'Y'/,NO/'N'/
4.000 NAMELIST
5.000 & L1,L2,L3,L4,L5,L6,L7,L8,LC,LS,D,WG,FTU,PHI,THETA,VSL,WL,NUMW,
MGR,NGR,
6.000 & NUMNT,IBTY
7.000 WRITE(108,33)
8.000 ANG1 = 0.
9.000 ANG2 = 0.
10.000 100 L1 = 0.
11.000 L2 = 0.
12.000 L3 = 0.
13.000 L4 = 0.
14.000 L5 = 0.
15.000 L6 = 0.
16.000 IBTY = 0
17.000 L7 = 0.
18.000 L8 = 0.
19.000 D = 0.
20.000 NUMNT = 0.
21.000 NUMW = 0.
22.000 INPUT(1)
23.000 IF(THETA.NE.ANG1) THETA=THETA*3.14159/180.
24.000 IF(PHI.NE.ANG2) PHI=PHI*3.14159/180.
25.000 ANG1=THETA
26.000 ANG2=PHI
27.000 IF(NUMNT.EQ.0.) NUMNT = 2.
28.000 IF(NUMW.EQ.0.) NUMW = 4.
29.000 IF(L1.EQ.0.) L1 = LC
30.000 IF(L2.EQ.0.) L2 = .2*LC
31.000 IF(L3.EQ.0.) L3 = .5*LS
32.000 IF(L4.EQ.0.) L4 = .5*LC
33.000 IF(L5.EQ.0.) L5 = 25.5
34.000 IF(L6.EQ.0.) L6=9.
35.000 IF(L8.EQ.0.) L8 = L4*TAN(PHI)
36.000 IF(L7.EQ.0.) L7 = L6+L3/TAN(THETA)-L8
37.000 IF(D.EQ.0.) D = 9.
38.000 IF(IBTY.EQ.1) GO TO 1314
39.000 BRKWT = (WL/128.8)*((1.6878*VSL)**2.)/200000.
40.000 GO TO 1315
41.000 1314 BRKWT = (WL/128.8)*((1.6878*VSL)**2.)/315000.
42.000 1315 CONTINUE
43.000 SP = MGR/NUMW
44.000 WTT = SP*.006875
45.000 TWTT = WTT*NUMW/2.
46.000 WH = SP/266.666667
47.000 TWH = WH*NUMW/2.
48.000 AXLES = TWH*.44226
49.000 VR=.5*WG*1.4
50.000 DP=.4*WG*1.4
51.000 VI = .4*VR
52.000 VV = .6 * VR
53.000 VC = (1./L7)*(VW*(L5+L8)-VI*(L5-L8))

```

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TABLE 3.4-3  
PROGRAM LISTING (Continued)

```

54.000 SC = VC/TAN(THETA)
55.000 VA = (1./L1)*(LS*DR-((VR+VC)*(L1/2.)))
56.000 VB = VR+VC+VA
57.000 MAA=.5*L1*(VA+VB)-L4*DR
58.000 AC = 1.26*((MAA/(.85*FTU))**(2.0/3.0))
59.000 RC = SQRT(AC/.596902604165)
60.000 WC = AC*(LC-L2)*.283
61.000 BRACE = .1*WC
62.000 B = 2.*RC-9.*SIN(PHI)
63.000 BETA = ATAN((L2+L4)/L1)
64.000 LA = (.5*L1-RC)/(COS(BETA)*COS(PHI))
65.000 MSIDE = (VB*COS(PHI)+SC*SIN(PHI))*COS(BETA)*LA
66.000 MFRONT = (VB*SIN(PHI)-SC*COS(PHI))*LA
67.000 FC = FTU
68.000 D1 = (729.-(54.*MSIDE)/(FC*(2.*RC-9.*SIN(PHI))))*(1./3.)
69.000 D4 = 6.*MFRONT/(4.*FC*RC*RC)
70.000 AF = (D-(D1-D4))*B+(D1-D4)
71.000 WFA = 1.05*AF*LA*.283*.5
72.000 MSIDE = ((VB*COS(PHI)+SC*SIN(PHI))*COS(BETA)-DR*SIN(BETA))*LA
73.000 DIP = (729.-(54.*MSIDE)/(FC*(2.*RC-9.*SIN(PHI))))*(1./3.)
74.000 AA = (D-(DIP-D4))*B+(DIP-D4)
75.000 WAA = 1.05*AA*LA*.283*.5
76.000 MP = DR*(LS-LC)
77.000 AP = 1.26*(MP/FTU)**(2./3.)
78.000 WP = 1.5*AP*LC*.283
79.000 TWSSC = WAA+WFA+WC+BRACE
80.000 ATF = .06*TWSSC**1.1
81.000 WT = TWSSC + WP+BRKWT+TWTT+AXLES+ATF+TWH
82.000 CONTRLS = .225*(WT**.95)
83.000 WT = WT + CONTRLS
84.000 THETA2 = THETA*180./3.14159
85.000 PHI2 = PHI*180./3.14159
86.000 SPN = NGR/NUMNT
87.000 WNT = SPN*.006875
88.000 TWNT = WNT*NUMNT
89.000 WHN = SPN/266.66667
90.000 AXLN = WHN*.44226
91.000 STN = TWSSC*.40
92.000 ATFN = .06*TWSSC**1.1
93.000 WING = TWNT+WHN+AXLN+STN+ATFN
94.000 CNTN = (WING**.95)*.850
95.000 WING = WING+CNTN
96.000 WRITE(108,33)
97.000 WC = WC*1.25
98.000 WFA = WFA*1.25
99.000 WAA = WAA * 1.25
100.000 BRACE = BRACE * 1.25
101.000 TWSSC = TWSSC * 1.25
102.000 AXLES = AXLES * 1.25
103.000 WP = WP * 1.25
104.000 CONTRLS = CONTRLS*1.25
105.000 ATF = ATF*1.25
106.000 BRKWT = BRKWT * 1.25

```



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TABLE 3.4-3  
PROGRAM LISTING (Continued)

```

107.000 TWTT = TWTT*1.25
108.000 TWH = TWH*1.25
109.000 WT = TWSSC+WP+BRKWT + TWTT+AXLES+ATF+TWH+CØNTRØLS
110.000 TWNT = TWNT*.80
111.000 WHN = WHN*.80
112.000 AXLN = AXLN*.80
113.000 STN = STN*.80
114.000 ATFN = ATFN*.80
115.000 CØNTN = CØNTN*.80
116.000 WING = TWNT+WHN+AXLN+STN+ATFN+CØNTN
117.000 WRITE(108,34) L1,L2,L3,L4,L5,L6,L7,L8,LC,LS,WG,FTU,THETA2,PHI2,
VSL,WL,
118.000 & NUMW,NUMNT,MGR,NGR
119.000 WRITE(108,105) WC,WFA,WAA,BRACE,TWSSC,BRKWT,TWTT,TWH,AXLES,AT
F
120.000 & ,CØNTRØLS,WP,WT
121.000 WRITE(108,106) TWNT,WHN,AXLN,STN,ATFN,CØNTN,WING
122.000 WRITE(108,33)
123.000 106 FØRMAT(19X, ' NØSE GEAR WEIGHT ',//
124.000 & 10X, ' TIRES AND TUBES = ',F9.2, ' LBS ',/,
125.000 & 19X, ' WHEELS = ',F9.2, ' LBS ',/,
126.000 & 20X, ' AXLES = ',F9.2, ' LBS ',/,
127.000 & 16X, ' STRUCTURE = ',F9.2, ' LBS ',/,
128.000 & 10X, ' ATTACH FITTINGS = ',F9.2, ' LBS ',/,
129.000 & 17X, ' CØNTRØLS = ',F9.2, ' LBS ',/,
130.000 & 20X, ' TØTAL = ',F9.2, ' LBS ',//)
131.000 33 FØRMAT(///)
132.000 105 FØRMAT(19X, ' MAIN GEAR WEIGHT ',//,17X, ' CYLINDER = ',F9.2,
' LBS ',/,
133.000 & 8X, ' FØRWARD PIVØT ARM = ',F9.2, ' LBS ',/,
134.000 & 12X, ' AFT PIVØT ARM = ',F9.2, ' LBS ',/,20X, ' BRACE = ',F9.2,
' LBS ',/,
135.000 & ' TØTAL SHØCK STRUT CYLINDER = ',F9.2, ' LBS ',/,19X, ' BRAKES =
'
136.000 & F9.2, ' LBS ',/,
137.000 & 10X, ' TIRES AND TUBES = ',F9.2, ' LBS ',/,19X, ' WHEELS = ',F9.2
' LBS ',/,
138.000 & 20X, ' AXLES = ',F9.2, ' LBS ',/,11X, ' ATTACH FITTINGS = ',F9.2,
' LBS ',/,
139.000 & 17X, ' CØNTRØLS = ',F9.2, ' LBS ',/,
140.000 & 7X, ' SHØCK STRUT PISTØN = ',F9.2, ' LBS ',/,
141.000 & 20X, ' TØTAL = ',F9.2, ' LBS ',//)
142.000 9996 CØNTINUE
143.000 ØUTPUT ' ARE YØU FINISHED? (Y ØR N) '
144.000 READ 5,ADD
145.000 5 FØRMAT(33A4)
146.000 IF(ADD.EQ.NØ) GØ TØ 100
147.000 34 FØRMAT( ' L1 = ',F6.2, '(IN) ',6X, ' L2 = ',F6.2,
' (IN) ',5X, ' L3 = ',F6.2, '(IN) ',/, ' L4 = ',F6.2,
' (IN) ',6X, ' L5 = ',F6.2, '(IN) ',5X, ' L6 = ',F6.2, '(IN) ',/,
' L7 = ',F6.2, '(IN) ',6X, ' L8 = ',F6.2, '(IN) ',/,
' LC = ',F6.2, '(IN) ',5X, ' LS = ',F6.2, '(IN) ',/,
' WG = ',F8.0, '(LBS) ',4X, ' FTU = ',F8.0, '(PSI) ',/,
' THETA = ',F6.2, '(DEG) ',3X, ' PHI = ',F6.2, '(DEG) ',/,
' VSTALL = ',F5.1, '(KNTS) ',2X, ' WL = ',F8.0, '(LBS) ',/,
' NUMW = ',F5.1, ' 10X, ' NUMNT = ',F5.1, ' /,
' MGR = ',F8.0, '(LBS) ',3X, ' NGR = ',F8.0, '(LBS) ',//)
157.000 STØP
158.000 END

```



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3.5 Propulsion Systems - The estimation models for the propulsion systems are analytically derived from Orbiter point designs. This section covers the Main Ascent Propulsion Systems and the Auxiliary Propulsion System. The Airbreathing Engine System (ABES) is considered a user-dependent system and the weight is user input.

3.5.1 Ascent Propulsion System - The ascent propulsion model essentially scales an Orbiter point design, using similar methods as those in the original analysis.

The feed lines are strength analyzed for the loads derived from the geometry, accelerations, and propellant densities. Line diameters and valve sizes on the baseline vehicle were predicated on the elastic response of the feed systems combined with propellant for the dynamic environment created by the engine start up and maximum thrust conditions. These system sizes are locked into the program for the basic point design and are scaled within the program for variations of thrust and number of engines to maintain constant full-thrust fluid velocities. Minimum gage criteria is locked into the program, allowing the user a variation of minimum thicknesses as a function of material. The program then calculates the weight of the feed lines for the critical parameter of strength analysis or minimum gage. The weight of bellows, valves, and couplings are based on curve fits of existing hardware data.

The secondary (by weight) subsystems are scaled by their individual critical parameters. Changes in concept or approach through a revised point design are accommodated by revising the input baseline weights and associated parameters. It is felt that the ratio approach is in accordance with the philosophy of minimum input for items which are not-major weight driven in the program.

The engine weight is based on a curve fit of actual data. An equation of the form  $W = CT^X$ , where  $W$  is the engine weight,  $C$  is a constant,  $T$  is the thrust, and  $X$  is the slope written for a log-log plot of comparable type engines, Figure 3.5-1. This curve is then "fit" through the basic point design engine weight with the exponent or slope input by the user.

Table 3.5-1, Input 104, is a listing and definition of the semipermanent variables representing the baseline point design vehicle. They are listed as separate inputs in the propulsion model, but are "locked in" the Orbiter Module program. This was done to reduce the number of required input variables in the program and overall simplification. If it is desired to modify any of these variables, the respective "card" in the module must be changed.

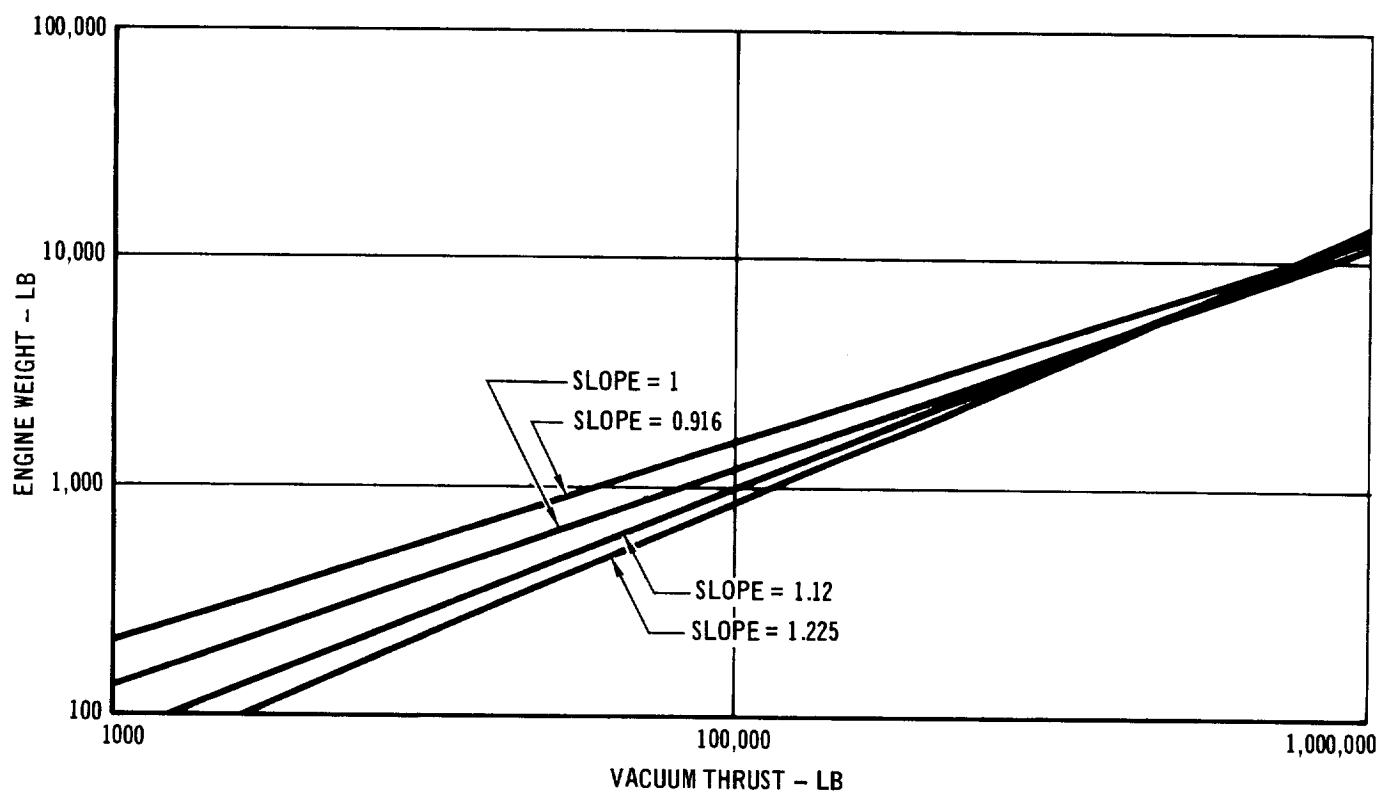


FIGURE 3.5-1 WEIGHT/THRUST RELATIONSHIP

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TABLE 3.5-1  
INPUT 104

Variable Name	
BENGNO	Number of ascent engines in baseline
BAENG	Baseline ascent engine weight
ESLP	Slope of line on log log paper thru engine wts
BETHST	Baseline ascent engine thrust (vac)
BPUTL	Propellant utilization system weight - baseline
BFAD	Fill and drain system weight - baseline
BPRES	Baseline pressurization system weight
BCHIL	Baseline chilldown dump lines
BRECIR	Baseline recirculation system weight
BDIAIN	Baseline engine inlet diameter
BPOGO	Baseline pogo increment per $O_2$ valve (valve penalty only)
BDIAD	Baseline external tank disconnect diameter ( $H_2$ )
GES	Maximum acceleration rate
SUPTF	% of valve, duct, and bellows wt needed for supports (as %)
HDOOR	Weight of disconnect cover door provisions $LH_2$
ODOOR	Weight of disconnect cover door provisions LOX
MISCF	% of main prop system less engine added for contingency

Table 3.5-2, Input 105, is the listing and definition of the input parameters which are expected to readily change in order to represent modifications in configurations.

Table 3.5-3 is a listing of test case input variables. Table 3.5-4 is the corresponding output. These are followed by a detail listing of the Ascent Propulsion Model (Table 3.5-5).

TABLE 3.5-2  
INPUT 105

Variable Name	
ETHST	Desired ascent engine thrust (vac) each
ENGNO	Number of ascent engines
POGO	Pogo suppression indicator POGO = 1 is yes POGO = 0 is no
SPI	Series/Parallel indicator SPI = 1 is series SPI = 0 is parallel
HHEAD	Height from top of H <sub>2</sub> tank to engine interface in inches
OHEAD	Height from top of O <sub>2</sub> tank to engine interface in inches
HULL	Hydrogen tank ullage pressure
OULL	Oxygen tank ullage pressure
FTU	Ultimate strength of duct material
RHO	Density of duct material
MATL	Min gage indicator (0) none (1) ARP735 & MDACW-STL(2) MDACW-AL (3) MSFC-AL (4) MSFC-STL
HCLN	Hydrogen-combined flow-length of ducts - inches
OCLN	Oxidizer-combined flow-length per side of ducts - inches
HELEN	Hydrogen-engine hook up - length of ducts - inches
OELN	Oxygen-engine hook up - length of ducts - inches
CPLGI	Coupling type ind CPLGI=0 is bolted CPLGI=1 is Vee-Bolt

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TABLE 3.5-3  
INPUT DATA

```

C011: MAIN1
*100-99
1.000  ENGNO=3.,BARME=57.7.,WGT=1.225,WTHTST=472000.,SPHIL=10.
2.000  HEAD=215.,BPRES=138.,BCHIL=133.,BRECLR=885.,SOTAIN=12.
3.000  PPGU=100.,BDIAD=17.,GES=3.,SOPTE=25.,HDDUR=50.
4.000  DDUR=50.,MISCF=10.
5.000  *
--END P11 AFTER 5.

```

```

C011: MAIN2
*100-99
1.000  WTHTST=472000.,ENGNO=3.,PPGU=1.,SPI=0.,HHEAD=996.
2.000  HEAD=135.7.,HULL=65.,BULL=30.,FTU=95000.,RHU=.286
3.000  WTL=1.,HOLEN=20.,COLEN=20.,HELEN=77.,CELEN=172.,CPLST=1.
4.000  *

```

TABLE 3.5-4  
OUTPUT

PROPULSION ASCENT	23782.
ENGINES & ACCESSORIES	19160.
ENGINES	17190.
GIMBAL SYSTEM	1222.
CONTROLS	738.
PROPELLANT UTILIZ.	10.
PROPELLANT SYSTEM	4622.
FILL & DRAIN	215.
PRESSURIZATION	188.
CHILL DOWN DUMP LINES	0.
PRE VALVES	1091.
FEED SYSTEM	2027.
DISCONNECTS	490.
MISCELLANEOUS	611.

\*STOP\* 0

TABLE 3.5-5  
ASCENT PROPULSION MODEL LISTING

```

9500.000      REAL MISC,MISCF,JAC
9501.000      NAMELIST
9502.000      %BENGND,BANG,BSLP,BETHST,BPUL,BFAD,BPRES,
9503.000      %BCHIL,BRECIR,BDIAD,BPSSD,BDIAD,GES,SUPIF,HDOOR,
9504.000      %HDOOR,MISCF,
9505.000      %ETHST,ENGND,PSSD,SPI,HREAD,GHEAD,HULL,
9506.000      %HULL,FTH,KFS,MAL,HULEN,OLEN,HELEN,
9507.000      %OLEN,CPLSI
9508.000      CALL EDEFSEI(9985)
9509.000      INPUT(104)
9510.000      INPUT(105)
9511.000      C      CALCULATE MAIN ENGINE WT.
9512.000      ECST=BANG/BETHST**ESLP
9513.000      ENG=ECST*ETHST**ESLP
9514.000      ENG=ENGND*ENGJ
9515.000      C      CALCULATE TVC WT.
9516.000      TVCU=.000422*ETHST+208.
9517.000      TVC=TVCU*ENGND
9518.000      C      CALCULATE IGNITION AND CONTROL WT.
9519.000      CONTR=377.+67.*ENGND+PSSD*ENGND*53.34
9520.000      C      CALCULATE PROPELLANT UTILIZATION SYS WT.
9521.000      BPUL=BPUL
9522.000      C      CALCULATE FILL AND DRAIN WT.
9523.000      FAD=BFAD
9524.000      C      CALCULATE PRESSURIZATION SYS WT.
9525.000      PRES=BPRES*((ETHST*ENGND)/(BETHST*BENGND))**.5
9526.000      C      CALCULATE CHILLDOWN DUMP SYS WT.
9527.000      CHIL=(BCHIL/BENGND)*(ETHST/BETHST)**.5*ENGND
9528.000      C      CALCULATE RECIRC SYS WT.
9529.000      RECIR=BRECIR*((ETHST*ENGND)/(BETHST*BENGND))**.5*SPI
9530.000      IF(SPI.EQ.0.) CHIL=0.
9531.000      C      CALCULATE PKE VALVE WT.
9532.000      DIAIR=BDIAIR*(ETHST/BETHST)**.5
9533.000      VALVE=1.582*DIAIR**1.78
9534.000      Q2PV=ENGND*(VALVE+PSSD*BPSSD)
9535.000      H2PV=ENGND*VALVE
9536.000      C      CALCULATE EAT TANK DISCONNECT WT.
9537.000      DIAO=BDIAO*((ETHST*ENGND)/(BETHST*BENGND))**.5
9538.000      DIAO=(.125*DIAO**2.0)**.5
9539.000      DIAO=SPI*(.5*DIAO**2.0)**.5
9540.000      IF(SPI.EQ.0.) DIAO=DIAO
9541.000      Q2OV=1.582*DIAO**1.78
9542.000      Q2OV=SPI**2.*1.582*DIAO**1.78
9543.000      IF(SPI.EQ.0.) Q2OV=H2OV
9544.000      C      CALCULATE FEED PUMP WT.
9545.000      HPRES=HULL+HREAD+GES*4.4/1728.
9546.000      GPRES=HULL+GHEAD+GES*71.7/1728.
9547.000      THD=HPRES*DIAD/FTH
9548.000      THDM=0.
9549.000      IF(MAL.EQ.1) THDM=.002*DIAD+.008
9550.000      IF(MAL.EQ.2) THDM=.003*DIAD+.010
9551.000      IF(MAL.EQ.3) THDM=.003*DIAD+.030
9552.000      IF(MAL.EQ.4) THDM=.002*DIAD+.024
9553.000      IF(THDM.GT.THDM) THD=THDM
9554.000      IQD=GPRES*DIADG/FTH
9555.000      IQDM=0.

```



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TABLE 3.5-5  
ASCENT PROPULSION MODEL LISTING (Continued)

```

9556.000      IF (MATL.EQ.1) T0DM=.002*DIAD0+.008
9557.000      IF (MATL.EQ.2) T0DM=.003*DIAD0+.010
9558.000      IF (MATL.EQ.3) T0DM=.003*DIAD0+.030
9559.000      IF (MATL.EQ.4) T0DM=.002*DIAD0+.024
9560.000      IF (T0DM.GT.T0D) T0D=T0DM
9561.000      THE=HPRES*DIAIN/FTU
9562.000      T0E=0PRES*DIAIN/FTU
9563.000      TEM=0.
9564.000      IF (MATL.EQ.1) TEM=.002*DIAIN+.008
9565.000      IF (MATL.EQ.2) TEM=.003*DIAIN+.010
9566.000      IF (MATL.EQ.3) TEM=.003*DIAIN+.030
9567.000      IF (MATL.EQ.4) TEM=.002*DIAIN+.024
9568.000      IF (THE.LT.TEM) THE=TEM
9569.000      IF (T0E.LT.TEM) T0E=TEM
9570.000      HDUCT=HCLEN*3.1416*DIAD*IH0*RHO
9571.000      &+HELEN*ENGNO*3.1416*DIAIN*THE*RHO
9572.000      JAC=HCLEN*(3.1416/2.)*(2.+DIAD)*3.1416*.012
9573.000      &*.286+HELEN*ENGNO*3.1416/2.*(2.+DIAIN)*3.1416
9574.000      &*.012*.286+(HCLEN*(1.+DIAD)*3.1416*1.
9575.000      &+HELEN*ENGNO*(1.+DIAD)*3.1416*1.)*5./1728.
9576.000      HDUCT=HDUCT+JAC
9577.000      CDUCT=0CLEN*3.1416*DIAD0*ICD*RHO*(1.+SPI)
9578.000      &+0ELEN*ENGNO*3.1416*DIAIN*T0E*RHO
9579.000      Y=.012
9580.000      Z=6.98
9581.000      IF (CPLGI.EQ.1.) Y=.126
9582.000      IF (CPLGI.EQ.1.) Z=6.24
9583.000      HCOUPL=2.*ENGNO*(Y*DIAIN+Z*.193*DIAIN)
9584.000      &+ENGNO*(Y*DIAIN+Z*(.286+RHO)*DIAIN/2.)
9585.000      &+ENGNO*(Y*DIAIN+Z*RHO*DIAIN)
9586.000      &+(Y*DIAD+Z*(1.+RHO)*DIAD/2.)
9587.000      X=(Y*DIAIN+Z*(.286+RHO)*DIAIN/2.)*ENGNO
9588.000      IF (RHO.GI..28) HCOUPL=HCOUPL-X
9589.000      CCOUPL=2.*ENGNO*(Y*DIAIN+Z*.193*DIAIN)
9590.000      &+ENGNO*(Y*DIAIN+Z*(.286+RHO)*DIAIN/2.)
9591.000      &+ENGNO*(Y*DIAIN+Z*RHO*DIAIN)
9592.000      &+(1.+SPI)*(Y*DIAD0+Z*(1.+RHO)*DIAD0/2.)
9593.000      X=(Y*DIAIN+Z*(.286+RHO)*DIAIN/2.)*ENGNO
9594.000      IF (RHO.GI..28) CCOUPL=CCOUPL-X
9595.000      X=INT(HCLEN/300.)
9596.000      HBEL0S=X*.04178*DIAD**2.1+ENGNO
9597.000      &*(.04178*DIAIN**2.1+2.*.01854*DIAIN**2.8)
9598.000      X=INT(0CLEN/300.)
9599.000      0BEL0S=X*.1475*DIAD0**2.05+ENGNO
9600.000      &*(.1475*DIAIN**2.05+2.*.03451*DIAIN**2.86)
9601.000      HSUPT=.01*SUPTF*(HCOUPL+H2PV+H2DV+HDUCT+HBEL0S)
9602.000      0SUPT=.01*SUPTF*(CCOUPL+02PV+02DV+0DUCT+0BEL0S)
9603.000      HDR=H00R
9604.000      0DR=000R
9605.000      02FD=0COUPL+0DUCT+0BEL0S+0SUPT+0DR
9606.000      H2FD=HCOUPL+HDUCT+HBEL0S+HSUPT+HDR
9607.000      C      CALCULATE MISC.WT.
9608.000      MISC=.01*MISCF*(TVC+C0NR+PRPUTL+FAD

```

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TABLE 3.5-5  
ASCENT PROPULSION MODEL LISTING (Continued)

```

9609.000      2+PRES+CHIL+RECIR+02PV+R2PV+H2DV+02DV
9610.000      2+02FD+H2FD)
9611.000 C    SUM DRY WT.
9612.000      ATOT=MISC/(.01*YMISC)+MISC+ENG

9614.000 C    MAIN ASCENT OUTPUT
9615.000      ENGPAC=ENG+IVC+CONTR+PRPUL
9616.000      PREVAL=02PV+R2PV
9617.000      FEEDS=02FD+H2FD
9618.000      DISC=02DV+H2DV
9619.000      PROSYS=FAD+PRES+CHIL+PREVAL+FEEDS+DISC+MISC
9620.000      TAPROP=ENGPAC+PROSYS
9621.000      WRITE(100,100) TAPROP,ENGPAC
9622.000      WRITE(100,200) ENG,IVC,CONTR,PRPUL
9623.000      WRITE(100,300) PROSYS
9624.000      WRITE(100,400) FAD,PRES,CHIL,PREVAL,FEEDS
9625.000      1,DISC,MISC
9626.000 100   FORMAT(/,20X,'PROPULSION ASCENT',8X,F10.0,/,
9627.000        1,21X,'ENGINES & ACCESSORIES',4X,F10.0)
9628.000 200   FORMAT(/,22X,'ENGINES',16X,F10.0
9629.000        1,/,22X,'SIMBAL SYSTEM',10X,F10.0
9630.000        2,/,22X,'CONTROLS',15X,F10.0
9631.000        3,/,22X,'PROPELLANT UTILIZ.',5X,F10.0)
9632.000 300   FORMAT(/,21X,'PROPELLANT SYSTEM',7X,F10.0)
9633.000 400   FORMAT(/,22X,'FILL & DRAIN',11X,F10.0
9634.000        1,/,22X,'PRESSURIZATION',9X,F10.0
9635.000        2,/,22X,'CHILL DOWN DUMP LINES',2X,F10.0
9636.000        4X,/,22X,'REFS. VALVES',11X,F10.0
9637.000        5,/,22X,'FEED SYSTEM',12X,F10.0
9638.000        6,/,22X,'DISCONNECTS',12X,F10.0
9639.000        7,/,22X,'MISCELLANEOUS',10X,F10.0)
9640.000 997   CONTINUE
9641.000      GO TO 1
9642.000 998   GO TO 999
9643.000 999   STOP
9644.000      END
--EOF HIT AFTER 9644.

```

3.5.2 Auxiliary Propulsion System - This model considers three subsystems: the engine assembly, propellant feed system, and propellant tankage for the Orbit Maneuvering System (OMS) and the Attitude Control System (ACS).

A review of the current NR system, Reference L, indicate a total weight of 6360 lb. Of this total, the tankage, including pressurization system, makes up approximately 55 percent of the basic auxiliary propulsion system weight.

This tankage is the primary configuration dependent variable, and received the analytical approach for estimation. The quantity of input variables required to define the engine weights and propellant system weights precludes the use of an analytical approach, and these weights are set by the user. In addition, the capability is built in for the user to input OMS module or ACS module weights into the Auxiliary Propulsion System Total if desired. If not, the option remains to input these installation modules into the Orbiter body, wing, or tail.

The OMS tanks are dependent on the orbit delta velocity required, on the Orbiter weight, and on the engine specific impulse. Using the standard rocket equation, the weight of propellant is easily solved. By inputting propellant densities and mixture ratio, the tanks are volumetrically sized. Assuming spherical tanks, combined with operating pressures and tank material properties, allows a simplified tank weight estimation.

The ACS tanks are handled quite similarly with the exception that the total propellant is a user input. Table 3.5-6 is a list of program variables along with their units and definitions. This is followed by Table 3.5-7, a typical input file, Table 3.5-8 typical output, and Table 3.5-9 a listing of the program.

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TABLE 3.5-6  
OMS VARIABLES

Symbol	Unit	Definition
OLOWLO	LB	Orbiter lift off weight less OMS propellant
OMSDVT	FT/SEC	OMS design $\Delta V$
OMSISP	SEC	Specific impulse of the OMS engine
OMR	ND	OMS propellant mixture ratio
DENSF	LB/FT <sup>3</sup>	Density of fuel
DENSO	LB/FT <sup>3</sup>	Density of oxidizer
PRESF	LB/IN <sup>2</sup>	Ullage pressure in fuel tank
PRESO	LB/IN <sup>2</sup>	Ullage pressure in oxidizer tank
FTUT	LB/IN <sup>2</sup>	Material allowable - tank
RHOT	LB/IN <sup>3</sup>	Material density - tank
PRESOM	LB/IN <sup>2</sup>	Ultimate pressure - tank pressurization system
RHOP	LB/IN <sup>3</sup>	Pressurization tank material density
FTUP	LB/IN <sup>2</sup>	Pressurization tank material allowable
MODULE	LB	Input OMS module weight
OMSENG	LB	Input OMS engine weight
PROPSY	LB	Input OMS system weight

ACS VARIABLES

Fortran Symbol	Unit	Definition
ACSPRO	LB	Input ACS propellant weight
ACSPRES	LB/IN <sup>2</sup>	Ullage pressure - ACS tank
ACSSYS	LB	Input ACS system weight
ACSENG	LB	Input ACS engine weight
ACSMOD	LB	Input ACS module weight
ACSDEN	LB/FT <sup>3</sup>	Density of the ACS propellant

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TABLE 3.5-7  
TYPICAL INPUT FILE

```
40.000 DENSF=54.7,DENS0=90.2,RHOT=.16,FTUT=135000.,PRES0M=8160.
41.000 RHOP=.16,FTUP=135000.,0MSENG=390.,PR0PSY=647.,M0DULE=1071.
42.000 PRESF=545.,PRES0=545.,ACSPR0=7280.,ACSDEN=61.3,ACSPRS=870.
43.000 ACSENG=1310.,ACSSYS=300.,ACSM0D=910.,0RBMIS=0.
```

TABLE 3.5-8  
TYPICAL OUTPUT

PROPULSION AUXILIARY		( 8166.)
ACS SYSTEM		3963.
THRUSTERS	1310.	
PROP. SYSTEM	300.	
TANK	1443.	
MODULE	910.	
CAMS SYSTEM		4204.
THRUSTERS	390.	
PROP. SYSTEM	647.	
TANK	2096.	
MODULE	1071.	

TABLE 3.5-9  
PROGRAM LISTING

```
630.000 C OMS SYSTEM CALCULATIONS
631.000 C
632.000 WTPROP=OLOHLO*(EXP(OMSDUT/(32.174*OMSISP))-1.)
633.000
634.000 WFUEL=WTPROP/(1.+OMR)
635.000 WOX=OMR*WFUEL
636.000 UFUEL=(WFUEL/DENSF)*1.15
637.000 UOX=(WOX/DENS0)*1.15
638.000 FTANK=3./2.*RHOT*PRESF*UFUEL/FTUT*1728.*1.28
639.000 OTANK=3./2.*RHOT*PRES0/FTUT*UOX*1728.*1.28
640.000 UPRES=(PRES0*UOX+PRESF*UFUEL)/PRES0M*1.47
641.000 PRESTK=3./2.*RHOP*PRES0M*UPRES/FTUP*1728.*1.28
642.000 WTMTK=FTANK+OTANK+PRESTK
643.000 WTOMS=WTMTK+OMSENG+PROPSY+MODULE
644.000 C ACS SYSTEM CALCULATIONS
645.000 ACSVOL=ACSPR0/ACSDEN*1.15
646.000 ACSTNK=3./2.*RHOT*ACSPRS*ACSVOL/FTUT*1728.*1.28
647.000 UPTNK=ACSVOL*ACSPRS/PRES0M*1.47
648.000 PTNK=3./2.*RHOT*PRES0M*UPTNK/FTUP*1728.*1.28
649.000 WTRACTK=(ACSTNK+PTNK)*1.25
650.000 WTACS=WTRACTK+ACSSYS+ACSENG+ACSMOD
651.000 WTAUX=WTOMS+WTACS
```



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3.6 Miscellaneous Systems - Empirical models are used to estimate the weight of the nonconfiguration dependent subsystems or those in which the detail of analysis required for an analytical model is not consistent with the program objectives of minimum input and rapid turnaround. Empirical models are used entirely for the following systems:

- a. thermal protection
- b. prime power
- c. electrical conversion and distribution
- d. hydraulic conversion and distribution
- e. surface controls
- f. avionics
- g. environmental control
- h. personnel provisions.

The models range in detail from the rather complex stacked pods method of area computations used in the thermal protection system, discussed in Section 3.3 to a total weight input as used for the avionics system.

The prime power system currently consists of batteries, an auxillary propulsion unit (APU), and fuel cells, with their associated mounting structures and tankage for expendables. The weights of these items are predicated on the specific power capabilities and the total power required. It would be easy to provide the specific power as an input in the orbiter module, but there is no simplified technique to determine total power requirements. This would necessitate inputting these also, and the program would only perform a bookkeeping function; therefore, it is felt that the additional six to eight input parameters were not justified and the prime power system weight would be determined outside the program and input by the user as a constant.

PPWR = 3912. for the reference design.

The electrical supply system currently consists of 411 lb of conversion and control units, 907 lb of utility systems and 346 lb of supports, plus 3681 lb of distribution and control circuitry. The primary configuration-dependent variable in this system is the circuitry, which is proportional to the vehicle length. In the sizing routines, the payload compartment length is allowed to vary for payload capability studies. This length is inherent in the program and will allow ratios without additional input variables. Assuming 50 percent of the circuitry is affected, the relationship becomes:

$$\text{ELEC} = \text{ELECK} + 1840 * (\text{LI-X}) / 747. + 2805.$$

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Where

ELEC is the system.

ELECK is an input weight to account for miscellaneous and special increments.

LI-X is the cargo bay length derived in the body model.

The hydraulic system primarily provides actuation capability for the surface controls and, therefore, becomes proportional to the areas of the wing and tail.

The weight then becomes:

$$\text{HYDR} = \text{HYDRK} + 2264 * (\text{SG}(1) + K * \text{SG}(2)) / 4525$$

where

HYDRK is an input constant to allow for special increments in the wing area

SG(1) is the wing area

SG(2) is the tail area

K is an indicator for a split rudder K = 1 for conventional

K = 3 for split rudder.

The surface control system weight is an empirical derivation based on the slope of an arithmetic plot of the actuation system. These systems include all actuators, plumbing, supports, and contingencies. Figure 3.6-1 is the elevon actuation weight and Figure 3.6-2 is the rudder actuation weight, both as a function of area. Combining these two figures, the relationship becomes:

$$\text{SURFC} = \text{SURFK} + 1060. + 3.45 * \text{SAIL} + K * (360. + 1.67 * \text{SRUD})$$

where

SURFK is a user input constant to apply special increments

SAIL is the elevon area

SRUD is the rudder area

K is an indicator to handle a split rudder K = 1 for conventional rudder and K = 3 for a split rudder.

The remaining systems making up the dry weight, avionics, environmental control, and personnel provisions are considered user inputs. The avionic system weight is governed by overriding factors of cost and state of the art and, as such, does not lend itself to normal weight estimation techniques. The personnel provisions are primarily governed by human-factor-type considerations as well as by the number of personnel and duration of the mission and like the prime power system, any estimation method would, inherently, be simple bookkeeping and the additional inputs required to accomplish this is not justified for a configuration sizing



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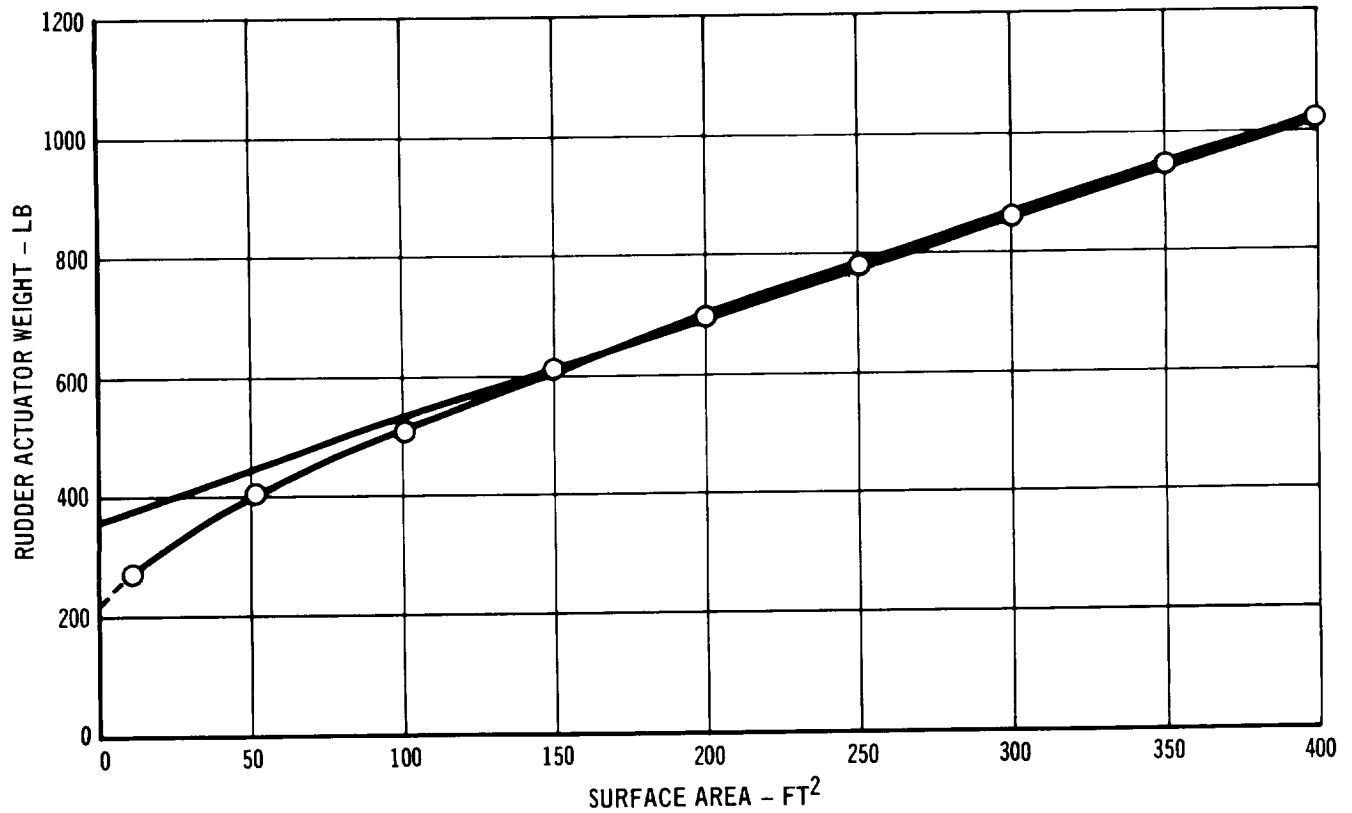


FIGURE 3.6-1 RUDDER ACTUATOR WEIGHT vs SURFACE AREA

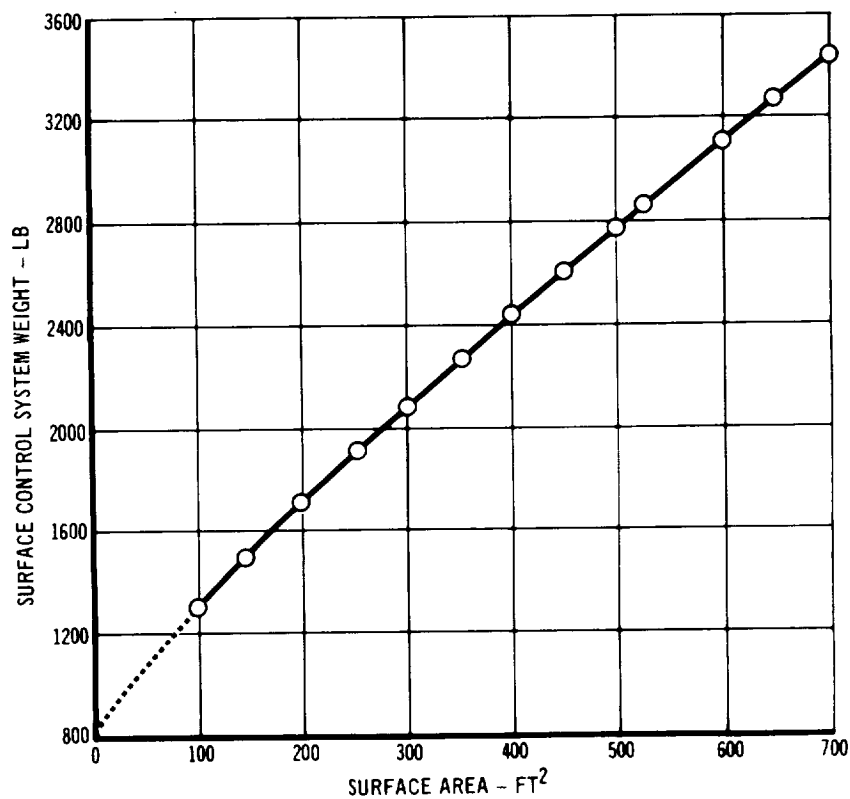


FIGURE 3.6-2 ELEVON ACTUATOR WEIGHT vs SURFACE AREA

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program. The environmental control system (ECS) is, in turn, sized by the heat and heat loss requirements of the avionics system and the life support provisions for the personnel provisions. It is considered a user input.

Growth uncertainty has the option for two methods of calculations. The first utilizes a fixed percentage of dry weight less the GFE ascent engines. This percent is input by the user. The second method allows the orbiter dry weight to remain at a user input fixed quantity. The growth uncertainty is allowed to float (increase or decrease as required) as the systems are analyzed by the various models.

#### 4. EXTERNAL TANK

4.0 Introduction - The External Tank Module contains many elements. These elements are interrelated to form an overall sizing routine which analytically solves for all the major components of the tank assembly. They are also versatile and accurate enough to allow assessment of even subtle variations in the basic design criteria. The basic sizing logic consists of three general arrangement options and three separate iteration techniques, i.e., solve for specific tank dimensions as a function of volume requirements with either input of fixed length, fixed diameter or fixed L/D. Design features, such as separate and common bulkheads and an alternate forward section design, are included in the three basic general arrangement options. This 3 by 3 matrix of sizing techniques has been tested for accuracy with two MDAC external tank point designs and the latest NR Design data contained in "Space Shuttle Mass Properties Status Report" No. SD72-SH-0120-S, dated 2 December 1972. A LOX aft option is also available which simply uses the generalized baseline LOX forward method and sets mixture ratio to 1./mixture ratio and switches the hydrogen and oxygen densities.

The external tank module also includes a design loads model which considers ullage and head pressure, interstage reactions, and axial load factors.

Also, a multistation analysis method is included, whereby a number of body station cuts are examined to determine the effective unit load and corresponding material thickness required for pure unstiffened monocoque structure. Alternate material allowables may be input to handle variations in design temperature and other candidate construction techniques. The resultant material thicknesses are integrated over the total body area using the dimensional data from the sizing routine, and the total sidewall weight is determined. The bulkheads are sized to their representative loads, i.e., internal or external pressure, considering meridional and hoop forces. Splice rings and attachment structure are treated as discrete items with major attention given to the redistribution of point loads and manufacturing processes such as welding.

The external tank thermal protection system is based on detailed MDAC point design data with input unit weights for alternate design concepts.

Other external tank subsystems are expressed either as input constants for such systems as avionics or with abbreviated sizing routines where, for example, plumbing weight is a function of engine flow rate and overall tank length/diameter.

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Detail loads, strength, and weight analyses are documented for the MDAC parallel burn 1,530,800-lb propellant load point design external tank. Therefore, this tank is used as the basis for the general methodology.

The basic structure and subsystems are correlated with the Phase B extension point design studies of external tanks as well as the latest NR point design tank. The overall Tank Model development is illustrated by Figure 4-1.

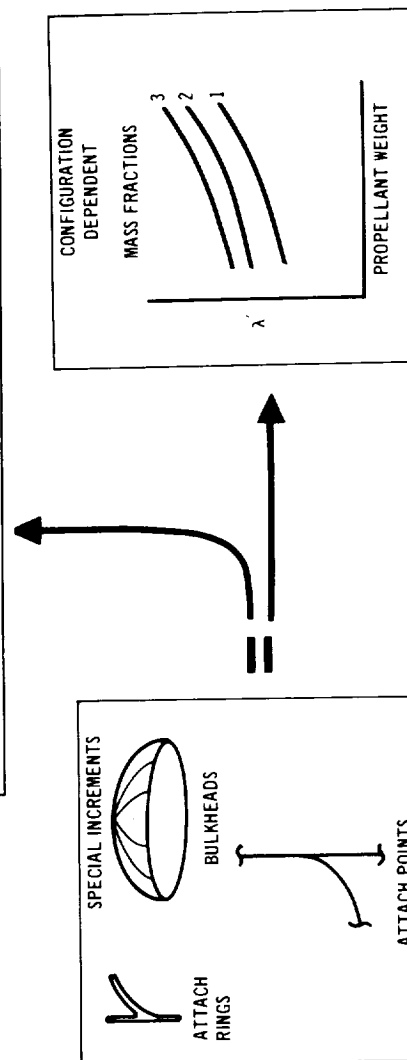
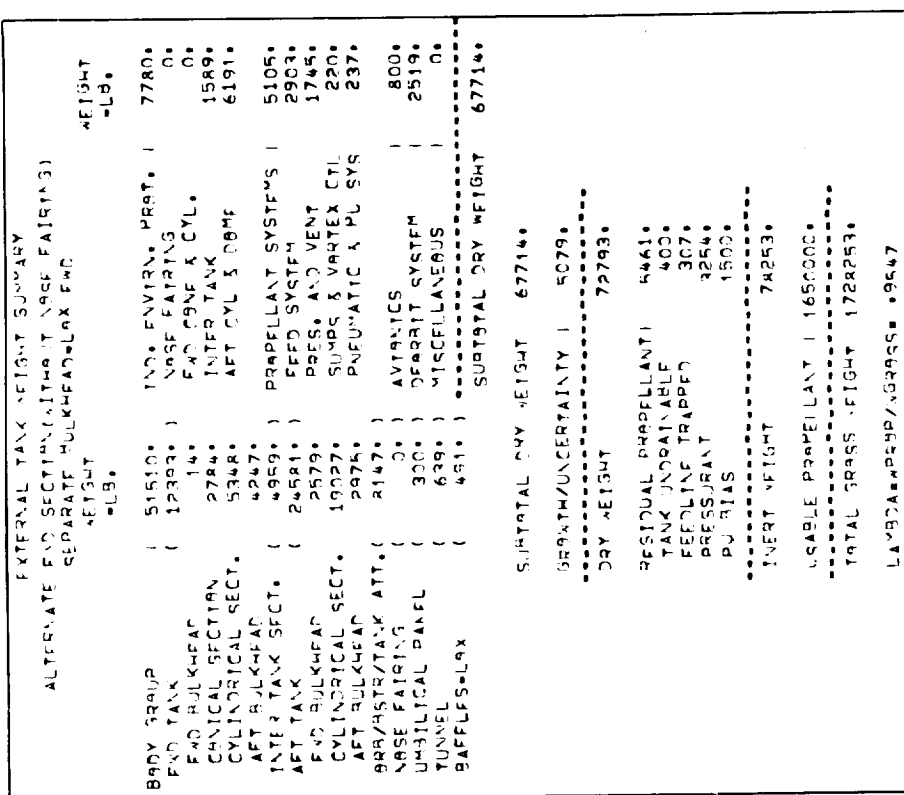
This External Tank Module is programmed so that it can be used as a separate program for individual tank studies, and is included as a subroutine of ESPER. Parametric computer runs have been made for a number of perturbations of the 2 December 1972 NR point design tank. The resulting computer output has been curvefit to express this external tank weight as a function of tank diameter, usable propellant load, and the ratio of second stage propellant to liftoff propellant. These simplified equations are also included as an option in ESPER.

The External Tank Module consists of 16 interdependent models and/or discrete sets of equations, each satisfying a specific piece of the overall sizing routine. These elements are discussed in detail in the following paragraphs (4.1 through 4.16).

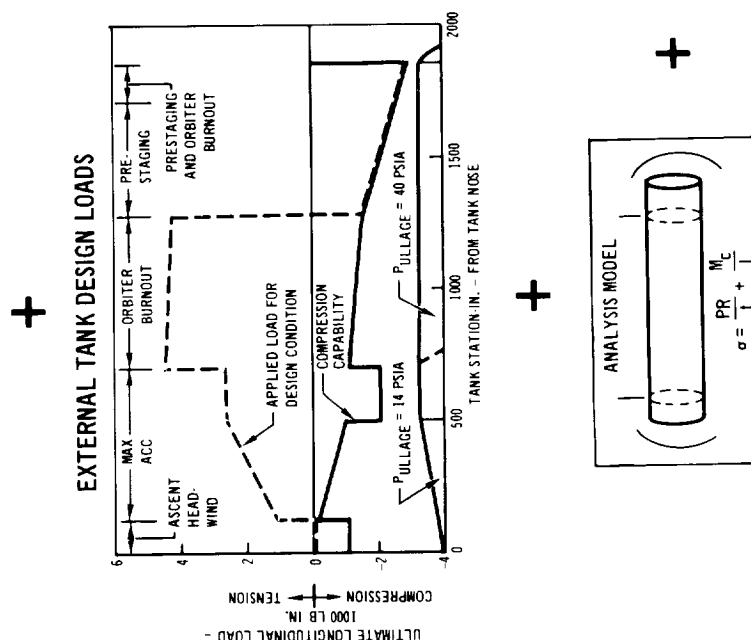
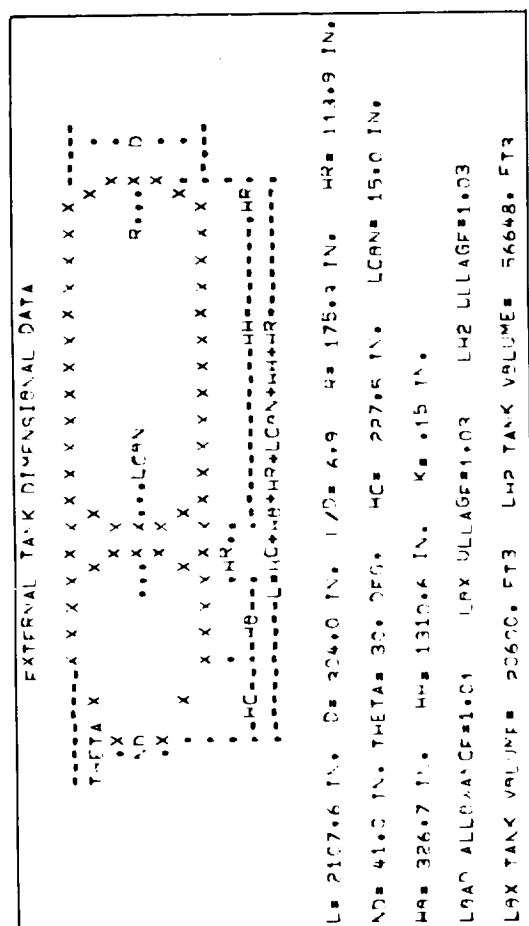
4.1 Volume Requirements - Contained within the sizing program are a series of equations to solve for a set of incremental propellant quantities which make up the tank residual and unusable fluids. This is necessary in order to obtain the correct total tank size required to contain all the propellant, as well as, to determine later the net effect of these residuals upon tank mass fraction. The trapped and residual fluids calculation alone is a very complex technical problem and normally requires a detailed examination of each point design for an accurate assessment. Therefore, a set of equations based on the MDAC detail point design analyses are used.

Key variations in design criteria can be measured by input of various ullage and operating pressures, orbiter engine thrust and ISP for basic feed-line sizing, variations in ullage and load allowance, as well as input variations in specific wall thickness for calculation of volume needed by the structure.

The MDAC point design propellant inventory and tank volume calculation which is used as the basis for these equations is shown in Table 4.1-1, along with the resulting computer program output. This illustrates the basic method used for assessing the tank volume. If comparable point design detail data become



### FIGURE 4-1 TANK MODEL DEVELOPMENT



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TABLE 4.1-1  
COMMON BULKHEAD - MDAC POINT DESIGN  
Propellant Inventory

	PROPELLANT WEIGHT-LB	
	TOTAL	
	LOX	LH <sub>2</sub>
ASCENT	1,312,114	218,686
START PROPELLANT	7,414	1,441
SHUTDOWN ADJUSTMENT	150	87
FEEDLINE RESIDUAL	918	285
CHILLDOWN RESIDUAL	134	6
ENGINE RESIDUAL	1,072	75
PU BIAS	0	547
TANK UNDRAINABLE	0	100
PRESSURANT	1,740*	795*
NOMINAL LOAD	1,323,544	222,022
LOADING ALLOWANCE	13,235	2,220
MAXIMUM LOAD	1,336,779	224,242
PROPELLANT BELOW TANK	-13,104	-366
MAXIMUM LOAD IN TANK	1,323,675	223,876
	VOLUME FT <sup>3</sup>	
PROPELLANT VOLUME IN TANK	18,643	50,939
TANK VOLUME FOR FLUIDS (2% MIN ULLAGE)	19,016	51,958
VOL DISPLACED BY INTERNAL LOX FEEDLINE	0	227
TOTAL TANK VOLUME	19,016	52,185

\*INCLUDES ONLY PRESSURANT FROM LIQUID.

Computer Output

EXTERNAL TANK PROPELLANT INVENTORY		
ITEM	LOX	LH <sub>2</sub>
PROPELLANT WEIGHT-LB.		
ASCENT (INCLUDES FPR)	1312114.	218686.
START PROPELLANT	7414.	1441.
SHUTDOWN ADJUSTMENT	150.	87.
FEEDLINE RESIDUAL	918.	285.
CHILLDOWN RESIDUAL	134.	6.
ENGINE RESIDUAL	1072.	75.
PU BIAS	0.	547.
TANK UNDRAINABLE	0.	100.
PRESSURANT	1740.	795.
NOMINAL LOAD	1323537.	222022.
LOADING ALLOWANCE	13236.	2220.
MAXIMUM LOAD	1336772.	224240.
PROPELLANT BELOW TANK	- 13092.	- 366.
MAXIMUM LOAD IN TANK	1323680.	223875.
PROPELLANT VOLUME-FT <sup>3</sup>		
PROPELLANT VOLUME IN TANK	18644.	50939.
TANK VOLUME FOR FLUIDS	19016.	51958.
VOL. DISPLACED BY LOX FEEDLINE	0.	227.
TOTAL TANK VOLUME	19016.	52125.

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available for other desired tank designs, new sets of equations can be derived to fit these cases using similar scaling laws for parametric study.

4.2 Dimensional Data - The three external tank general arrangement options used in the basic tank sizing routine are illustrated in Figure 4.2-1. The sizing logic nomenclature is defined in Table 4.2-1. It should be noted that most of the basic dimensional parameters have the same variable name for each of the three arrangements given. Therefore, most of the sizing equations are identical for each option and only a few input variables need be changed to switch from one general arrangement to the other. For example, the variable LCON (input clearance between separate bulkheads) is not used for the common bulkhead option; otherwise, all other parameters are the same. Likewise, when choosing the alternate forward section option, the user need only switch the input from NR (nose cap radius) to ND (nose diameter). All other parameters remain the same.

An indicator and logical IF statement is included which offers the option of solving for LOX aft tank arrangements. This consists of simply converting MR to  $1/\text{MR}$  and setting LOX density equals  $\text{LH}_2$  density and vice versa. Thus, the logical IF simply tells the computer all equations and dimensions used for LOX are now  $\text{LH}_2$  and vice versa.

Computer diagnostic runs have been made to exercise the sizing logic of the program and demonstrate dimensional accuracy and repeatability for each of the sizing options. Resulting propellant inventories and corresponding dimensional data computer output are shown in Tables 4.2-2 and 4.2-3. The MDAC point design dimensional data are shown in Figure 4.2-2, along with the comparable computer program output.

4.3 Head Pressures - The propellant inventory, volume requirements and basic dimensional data previously discussed serve as the basis for the head pressure calculations. The input data required for the head pressure analysis are described in Table 4.3-1. The basic method of analysis, and the nomenclature, is illustrated in Figure 4.3-1.

Since the basic sizing routine allows excess volume for ullage space, etc., the actual maximum fluid height in the tank at liftoff is located somewhat below the top of the tank. This space is dependent upon the input percent ullage, etc., and, therefore, may vary significantly. Hence, the actual fluid height in the tank at liftoff is calculated. The fluid height is used to determine the gross head pressure on both the aft LOX and  $\text{LH}_2$  bulkheads, using the design factor of safety (FS), liftoff vertical load factor (NXL), and fluid density (ODEN or FDEN).

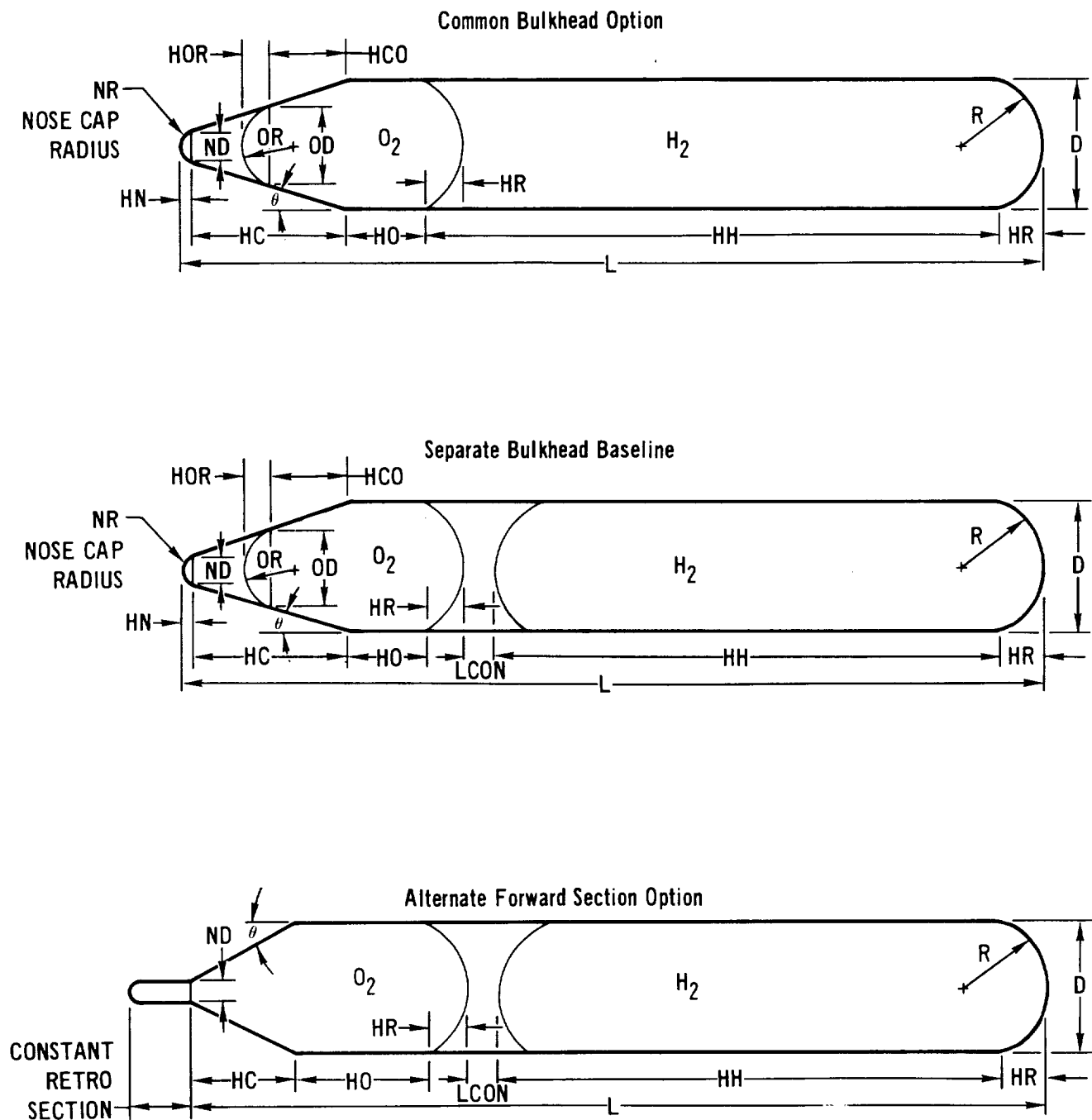


FIGURE 4.2-1 EXTERNAL TANK GENERAL GEOMETRY DESCRIPTION



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TABLE 4.2-1  
EXTERNAL TANK SIZING NOMENCLATURE

VARIABLE NAME	DEFINITION	UNITS
INPUT PARAMETERS		
PROPO	Usable Propellant Load	LB
MRI	Mixture Ratio; Oxidizer/Fuel	ND
NR, ND	Nose Cap Radius and/or Nose Diameter	IN
HRI	Ratio of Bulkhead Height to Bulkhead Hemispherical Radius - HR/R	ND
THETA	$\theta$ Forward Cone Angle	DEG
LA	Load Allowance (1 + Dec. %)	ND
UPERO	Percent Oxidizer Ullage (1 + Dec. %)	ND
UPERF	Percent Fuel Ullage (1 + Dec. %)	ND
OPRES, OUPRES	Oxidizer Pressure Operating, Ullage	Lb/In <sup>2</sup>
FOPRES, FUPRES	Fuel Pressure Operating, Ullage	Lb/In <sup>2</sup>
THRO, ISPOT	Orbiter Eng. Thrust, ISP for Flow Required	Lb, Sec
BLKHD	Ind. 1 = Common; 2 = Separate; 3 = Alternate	--
BX	Dummy Ind. to Test Series Burn Pt. Design	--
LCON	Clearance Between Bulkheads	IN
K	Structural Space Allowance	IN
HBIAS	Optional Fixed Fuel Bias	LB
GEOMETRY SOLUTION		
INPUT OPTIONS		
LD	Required L/D - Output is Resultant Length and Diameter	ND
LF	Required Fixed Length - Output is Resultant Diameter	IN
DF	Required Fixed Diameter - Output is Resultant Length	IN
INPUT REQUIRED FOR INITIALIZATION		
DI	Initial Guess at Tank Diameter	IN
LI	Initial Guess at Tank Length	IN
HHI	Initial Guess at Fuel Tank Length	IN

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TABLE 4.2-2  
ORBITER HQ TANK PROPELLANT INVENTORY  
COMPUTER OUTPUT VERSUS POINT DESIGN DATA

	MDAC-COMMON BULKHEAD-PARALLEL BURN				MDAC-SEPARATE B	
	POINT DESIGN DATA		COMPUTER OUTPUT		POINT DESIGN DATA	
	LOX	LH <sub>2</sub>	LOX	LH <sub>2</sub>	LOX	LH <sub>2</sub>
**ASCENT (INPUT TO COMPUTER)	1,312,114	218,686	1,312,114	218,686	807,514	134,58
START PROPELLANT	7,414	1,441	7,414	1,441	1,014	37
SHUTDOWN ADJUSTMENT	150	87	150	87	150	8
FEEDLINE RESIDUAL	918	285	918	284	1,522	27
CHILLDOWN RESIDUAL	134	6	134	6	273	2
ENGINE RESIDUAL	1,072	75	1,072	75	1,072	7
PU BIAS	0	547	0	547	0	33
TANK UNDRAINABLE	0	100	0	100	300	10
PRESSURANT	1,740	795	1,740	795	1,068	47
NOMINAL LOAD	1,323,544	222,022	1,323,537	222,020	812,913	136,33
LOADING ALLOWANCE	13,235	2,220	13,236	2,220	8,129	1,36
MAXIMUM LOAD	1,336,779	224,242	1,336,772	224,240	821,042	137,69
PROPELLANT BELOW TANK	-13,104	-366	-13,082	-365	-13,852	-37
MAXIMUM LOAD IN TANK LB.	1,323,675	223,876	1,323,690	223,875	808,190	137,32
	VOLUME FT <sup>3</sup>		VOLUME FT <sup>3</sup>		VOL	
PROPELLANT VOLUME IN TANK	18,643	50,939	18,644	50,881	11,383	31,24
TANK VOL FOR FLUIDS	19,016	51,958	19,016	51,898	11,611	31,87
VOL. DISPLACED FOR LOX FEEDLINE	0	227	0	227	0	
TOTAL TANK VOLUME	19,016	52,185	19,016	52,125	11,611	31,87

\*\* INCLUDES FPR. INPUTTED TO COMPUTER AS TOTAL USEABLE PROPELLANT LOAD AND MIXTURE RATIO.

FOLDOUT FRAME /



BULKHEAD-SERIES BURN			NR-SEPARATE BULKHEAD-PARALLEL BURN			
A	COMPUTER OUTPUT		POINT DESIGN DATA		COMPUTER OUTPUT	
	LOX	LH <sub>2</sub>	LOX	LH <sub>2</sub>	LOX	LH <sub>2</sub>
6	807,514	134,586	1,414,290	235,710	1,414,285	235,714
2	1,015	372	?	?	7,411	1,440
7	150	87			150	87
7	918	260			918	252
3	272	19			134	6
5	1,072	75			1,072	75
6	0	336		1,500	0	1,500
0	300	100			300	100
8	1,071	489	?	?	2,084	750
<hr/>						
4	812,312	136,324	1,420,230	239,350	1,426,349	239,924
3	8,123	1,363	?	?	14,264	2,399
<hr/>						
7	820,435	137,687	?	?	1,440,612	242,323
5	-13,142	-354	?	?	-20,570	-333
<hr/>						
2	807,292	137,333	?	?	1,420,041	241,990
<hr/>						
VOLUME FT <sup>3</sup>			VOLUME FT <sup>3</sup>			
5	11,370	31,212	20,114	55,517	20,001	54,998
0	11,598	31,836	20,710	57,157	20,595	56,648
0	0	0	0	0	0	0
<hr/>						
0	11,598	31,836	20,710	57,157	20,595	56,648

~~WOLDOUT FRAME~~

FOR REMOVAL

2



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TABLE 4.2-3  
EXTERNAL TANK BASIC DIMENSIONAL DATA  
COMPUTER OUTPUT VERSUS POINT DESIGN

BASIC DIMENSIONS SEE FIGURE 4-3	MDAC-COMMON BULKHEAD-PARALLEL BURN				MDAC-SEPARATE BULKHEAD-SERIES BURN				NR-S POI DESI DAI
	POINT DESIGN DATA	COMPUTER OUTPUT			POINT DESIGN DATA	COMPUTER OUTPUT			
		FIXED L/D	FIXED LENGTH	FIXED DIA.		FIXED L/D	FIXED LENGTH	FIXED DIA.	
L/D	4.982	4.982*	--	--	4.682	4.682*	--	--	7.11
D(O.D.)	340.0	339.6	339.2	340.0*	314.0	310.2	306.3	314.0*	304
L(TOTAL)	1694.0	1692.0	1694.0*	1689.5	1470.0	1452.0	1470.0*	1434.5	2162
R	196.0	196.1	195.8	196.3	181.0	179.1	176.9	181.3	?
HR	98.0	98.0	97.9	98.1	91.0	89.5	88.4	90.6	114
HH	996.0	994.2	996.7	992.1	703.0	718.0	736.6	700.4	132
HO	180.0	181.3	182.5	180.3	42.0	50.6	60.1	41.5	204
HC	403.6	402.0	401.4	402.5	469.0	459.9	452.7	467.0	372
HN	16.4	16.4	16.4	16.4	24.0	24.5	24.5	24.5	--
NR	25.0	25.0*	25.0*	25.0*	33.0	33.0*	33.0*	33.0*	--
ND	?	47.0	47.0	47.0	?	63.8	63.8	63.8	42
OR	128.0	128.7	128.6	128.8	106.0	104.1	103.1	105.1	--
OD	221.4	222.9	222.7	223.1	?	180.3	178.5	182.1	--
HOR	64.0	64.4	64.3	64.4	53.0	52.1	51.5	52.6	--
HCO	163.0	160.3	160.1	160.5	243.0	242.4	238.6	246.1	--
θ	20.0	20.0*	20.0*	20.0*	15.0	15.0*	15.0*	15.0*	?
LCON	--	--	--	--	20.0	20.0*	20.0*	20.0*	3
LO <sub>2</sub> TK VOL	19016	19016	19017	19017	11611	11598	11594	11600	207
LH <sub>2</sub> TK VOL	52185	52125	52125	52124	31870	31836	31836	31836	571
K	--	--	--	--	--	--	--	--	.

(K equals structural volume allowance expressed as effective wall thickness)

\*Indicates input value

(1) NR Point design has an ogive nose shape instead of a conical nose shape, therefore, an estimated forward cone angle ( $\theta$ ) has been used to represent an equivalent conical section volume.

FOLDOUT FRAME 1





SEPARATE BULKHEAD-PARALLEL BURN  
 NT ALTERNATE FWD SECT.  
 GN COMPUTER OUTPUT

A	FIXED L/D	FIXED LENGTH	FIXED DIA.
2	7.112*	--	--
.0	301.8	300.5	304.0*
.0	2146.9	2162.0*	2122.5
	174.1	173.3	175.3
.0	113.1	112.6	113.9
8.0	1330.4	1342.7	1310.6
.0	334.8	339.8	326.6
.0	225.6	224.5	227.5
	--	--	--
	--	--	--
.0	41.0*	41.0*	41.0*
	--	--	--
	--	--	--
	--	--	--
	30.0*	30.0*	30.0*
.0	30.0*	30.0*	30.0*
.0	20595	20592	20598
7	56648	56648	56648
5	.15*	.15*	.15*

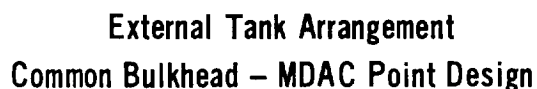
(1)

FOLDOUT FRAME

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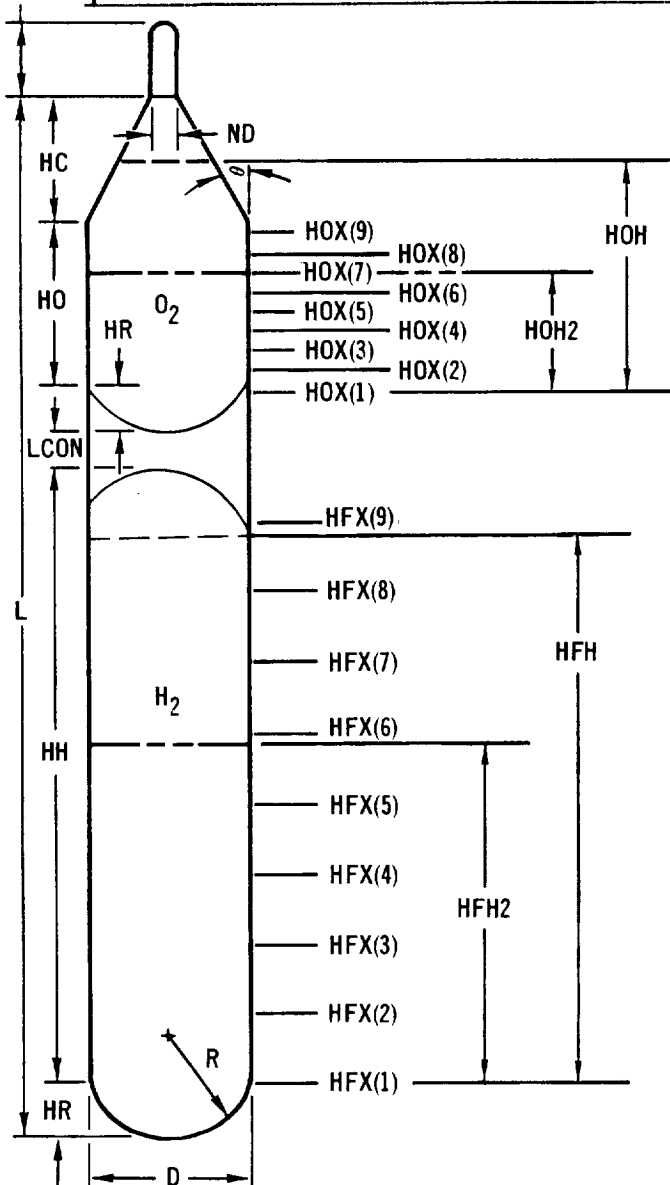
**Computer Output**  
**Fixed L/D Case**

**MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - EAST**

TABLE 4.3-1  
EXTERNAL TANK  
INPUT DATA FOR HEAD PRESSURE ANALYSIS

VARIABLE NAME	DEFINITION	UNITS
PROPO2	USEABLE PROPELLANT REQUIRED FOR SECOND STAGE BURN	LB
NXL	VERTICAL LOAD FACTOR AT LIFTOFF	ND
NXS	VERTICAL LOAD FACTOR AT STAGING	ND
FS	DESIGN FACTOR OF SAFETY	ND

CONSTANT  
RETRO  
SECTION



ODEN = OXYGEN DENSITY - LB/FT<sup>3</sup>

HOH = OXYGEN FLUID HEAD HEIGHT AT LIFT-OFF

HOH2 = OXYGEN FLUID HEAD HEIGHT AT STAGING

SET STATION LOCATIONS FOR OXY TANK CYL WALL ANALYSIS

HOX(I) = .125 \* (I-1) \* HO

CALCULATE OXY TK CYL WALL HEAD PRES AT HOX(I)

ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND 2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY

OHC2 = (HOH2 - HOX(I)) \* ODEN \* NXs \* FS/1728.

OHC1 = (HOH - HOX(I)) \* ODEN \* NXL \* FS/1728.

FDEN = LH2 DENSITY - LB/FT<sup>3</sup>

HFH = LH2 FLUID HEAD HEIGHT AT LIFT-OFF

HFH2 = LH2 FLUID HEAD HEIGHT AT STAGING

HF = HH - HR

SET STATION LOCATIONS FOR FUEL TANK CYL WALL ANALYSIS

HFX(I) = .125 \* (I-1) \* HF

CALCULATE FUEL TK CYL WALL HEAD PRES AT HFX(I)

ABOVE CYL BASE BY COMPARING WITH LIFT-OFF AND 2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY

FHC2 = (HFH2 - HFX(I)) \* FDEN \* NXs \* FS/1728.

FHC1 = (HFH - HFX(I)) \* FDEN \* NXL \* FS/1728.

FIGURE 4.3-1 EXTERNAL TANK HEAD PRESSURE ANALYSIS AND NOMENCLATURE

Using the input value for the amount of propellant required for second stage burn (PROPO2), a similar calculation of the fluid head height at staging is made. The gross head pressure at staging is then determined, using the design factor of safety (FS), vertical load factor at staging (NXS), and fluid density (ODEN or FDEN). The liftoff head pressure is then compared with the head pressure at staging and the maximum design head pressure is set equal to the larger of the two values. This maximum head pressure, plus the ultimate tank operating pressure, yields the design maximum pressure used for the LOX and LH<sub>2</sub> aft bulkhead sizing analysis.

Similarly, head pressures are calculated at nine stations along the forward LOX tank cylinder wall and the aft LH<sub>2</sub> tank cylinder wall. For example, the liftoff fluid head acting at any station HFX (I) of Figure 4.3-1 can be calculated by comparing its location with the liftoff LH<sub>2</sub> head height (HFH). The net distance between HFX (I) and HFH represents the effective head height experienced at HFX (I). Thus, the net liftoff head pressure at HFX (I) is calculated using this net distance (HFH-HFX (I)), the design factor of safety (FS), liftoff vertical load factor (NXL), and fluid density (FDEN). Similarly, the fluid head at staging is calculated using the net fluid height (HFH<sub>2</sub> - HFX (I)), the design factor of safety (FS), vertical load factor at staging (NXS), and fluid density (FDEN). A comparison is made at each of the cylinder stations and the maximum head pressure is set equal to the greater of the two values calculated. This value plus the ultimate tank operating pressure, establishes the design maximum pressure at the cylinder station HFX (I). If HFX (I) is above both HFH and HFH<sub>2</sub> (as could be the case for the station HFX (9) of Figure 4.3-1, the net head pressure is set to zero and the design maximum pressure is set equal to the ultimate tank operating pressure.

Similarly, the forward LOX tank cylinder wall pressures are determined as illustrated by Figure 4.3-1. Thus, a complete survey of tank design pressures is available for use in the multistation strength analysis which is discussed below.

4.4 Wall Thickness - The design maximum pressures previously discussed serve as the basis for calculating the required cylinder wall thickness due to hoop stress. The structural material properties required as input are given in Table 4.4-1. The basic method of material thickness calculation is given in Table 4.4-2. As shown by Table 4.4-2, the wall thickness required due to hoop stress is calculated at each cylinder station, and compared with an input minimum thickness (TMIN).

(I) **TABLE 4.4-1**  
**EXTERNAL TANK INPUT OF**  
**STRUCTURAL MATERIAL PROPERTIES**

VARIABLE NAME	DEFINITION	UNITS
RHO	MATERIAL DENSITY	LB/IN. <sup>3</sup>
FTU	MATERIAL ULTIMATE TENSILE STRENGTH	PSI
E	MATERIAL MODULUS OF ELASTICITY	PSI
TMIN	MATERIAL MINIMUM GAUGE	IN.

**TABLE 4.4-2**  
**EXTERNAL TANK CYLINDER WALL**  
**MATERIAL THICKNESS REQUIRED BY HOOP STRESS**

REFERENCE: FIGURE 4.3-1

FHCT(I) = ULTIMATE LH<sub>2</sub> TANK CYLINDER WALL PRESSURE  
AT STATION HFX(I)

OHCT(I) = ULTIMATE LOX TANK CYLINDER WALL PRESSURE  
AT STATION HOX(I)

CALCULATE FUEL TK THICKNESS REQUIRED DUE TO ULT PRES  
TF(I) = FHCT(I)\*D\*.5/FTU  
CALCULATE OXY TK THICKNESS REQUIRED DUE TO ULT PRES  
TO(I) = OHCT(I)\*D\*.5/FTU  
CHECK FUEL TK THICKNESS & SET = OR GREATER THAN TMIN  
IF(TF(I).LT.TMIN) TF(I) = TMIN  
CHECK OXY TK THICKNESS & SET = OR GREATER THAN TMIN  
IF (TO(I).LT.TMIN) TO(I) = TMIN

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4.5 Loads - As illustrated by Figure 4.5-1, only a small portion of the over-all tank structure is designed by loads other than internal pressure. Launch aerodynamic and inertial loads normally require a very complex technical analysis for accurate assessment. A generalized set of equations is used to depict launch axial loads and bending moments. These are based on MDAC detailed point design loads analysis. Axial loads induced in the aft LH<sub>2</sub> tank are based on the LOX liftoff and second stage propellant loads and their respective vertical load factors (as discussed previously).

If comparable point design detail loads become available for other desired tank designs, new sets of equations can be derived to fit these cases.

The method of scaling these loads through perturbations of the baseline tank design are considered adequate, especially since only a small portion of the over-all tank structure is designed for column buckling due to these loading conditions.

Table 4.5-1 defines the required input data for loads calculations.

TABLE 4.5-1  
EXTERNAL TANK  
INPUT DATA FOR LOADS CALCULATION

VARIABLE NAME	DEFINITION	UNITS
THBSL	TOTAL BOOSTER S.L. THRUST	LB
NN	NUMBER OF BOOSTER ENGINES	ND
CANT	BOOSTER THRUST CANT ANGLE	DEG
BGLOW	BOOSTER GROSS LIFTOFF WEIGHT	LB
R1, R2, RL	ORBITER INTERSTAGE REACTION LOADS FROM ORBITER MODULE	LB

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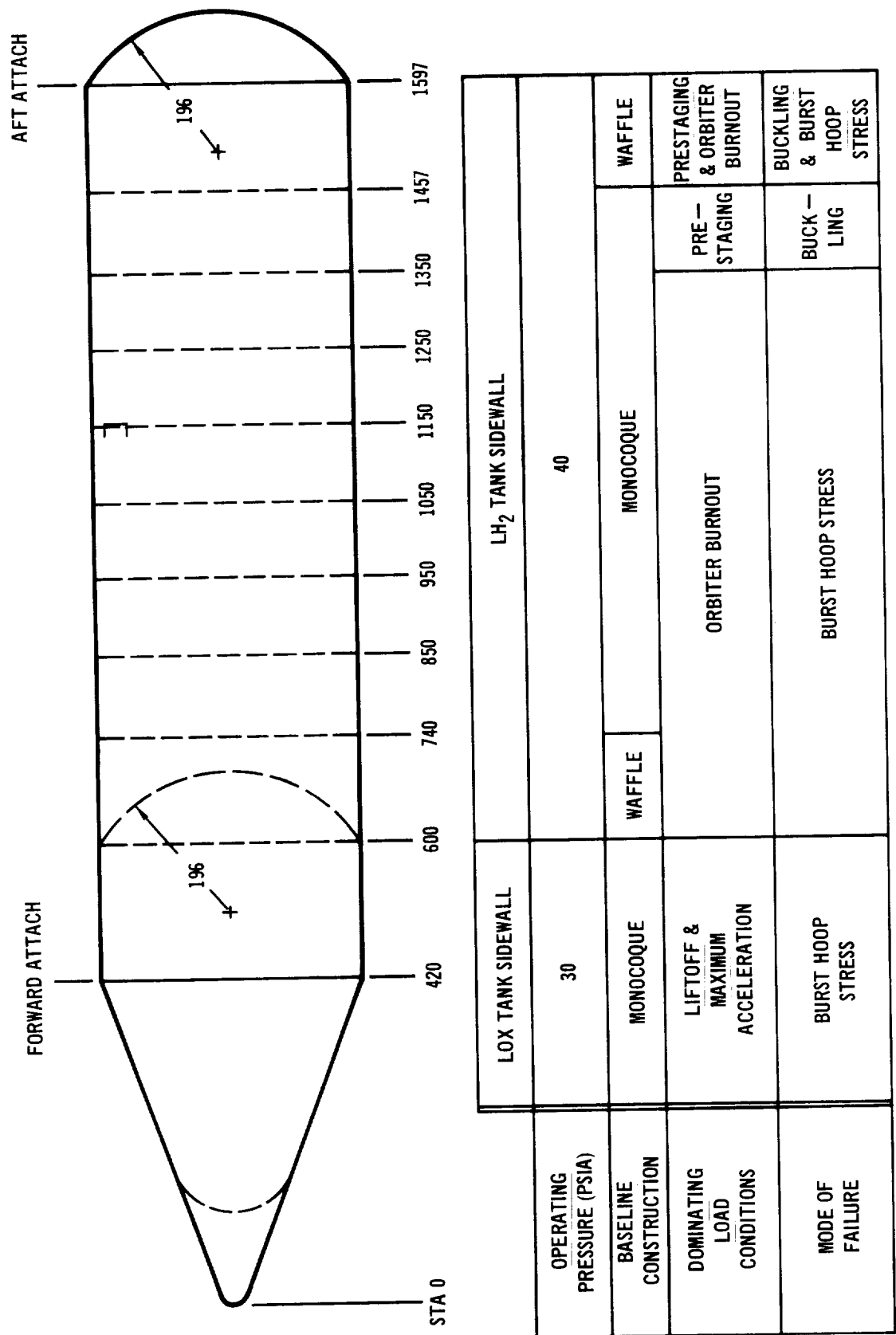


FIGURE 4.5-1 STRUCTURAL DESIGN CONDITIONS TWIN RAO (2-156 SRM) HO TANK



4.6 Margin-of-Safety Check for Column Buckling - A margin-of-safety check is made at each of the body stations previously analyzed, using the wall thickness calculated for hoop stress due to head pressure.

The column buckling method for monocoque cylinders as given by Reference 0 is used for the combined axial load and bending moment loading condition with internal pressure stabilization. Included in this analysis is a least squares curve fit for the 90 percent probability graphs of cylinder radius/material thickness ( $r/t$ ) versus critical stress due to axial load and  $r/t$  versus critical stress due to bending moment. This curve fit solves for equation coefficients as a function of cylinder length/cylinder radius ( $L/r$ ).

Included also are equations to solve for increased axial and bending strength due to internal pressure stabilization. These equations are derived from curves included in Reference 0. The internal pressure is assumed to be the tank operating pressure without the design factor of safety and without any induced head pressure.

The margin of safety, then, is calculated by:

$$RCB = AL/PA + MX/MA$$

Where: AL = The maximum axial load induced at a given station per the previous loads analysis.

PA = The amount of axial load that can be imposed at this station with the thickness as previously calculated due to hoop stress, including increased strength capability due to internal pressure and with a 90 percent probability of not failing.

MX = The maximum bending moment induced at this station per the previous loads calculation.

MA = The bending moment that can be imposed at this station with the thickness previously calculated for hoop stress including increased strength due to internal pressure and with a 90 percent probability of not failing.

If this margin of safety (RCB) is less than one, the check is satisfied and the previously calculated wall thickness for hoop stress is adequate to withstand the column buckling condition. If not, the thickness is progressively increased until this check is satisfied, and the new wall thickness thus calculated is used for the final cylinder wall weight calculation.

4.7 Rings - Bulkhead attachment and cylinder/cone contour break rings are sized by elastic stability (Reference C), due to resultant compressive load induced by dome pressure and/or longitudinal cylinder stress. The resulting ring cross sectional area is compared with the required minimum ring area shown in Figure 4.7-1 and is set equivalent to or greater than this minimum.

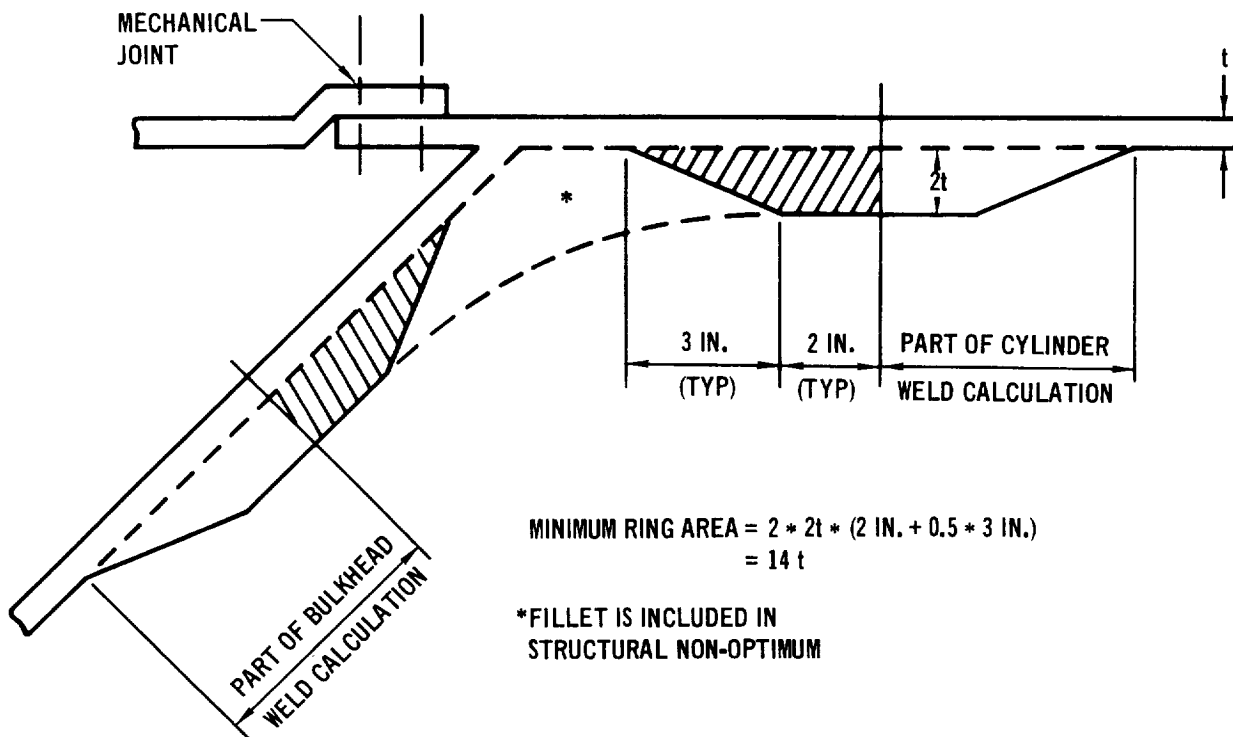


FIGURE 4.7-1 TYPICAL BULKHEAD ATTACH RING

4.8 Interstage - Frame sizing is based on point load analysis for ring caps plus resulting shear stress for ring webs. Additional material is added for beam cap loads and beam shear. The booster attach loads are assumed acting at the existing aft bulkhead attach ring and at the forward cone/cylinder contour break ring. The resulting booster attach frame sizing is compared with the previously calculated existing ring. The interstage frame weight is set equal to zero if the attach frame is less than the existing ring; otherwise, it is set equal to the difference in frame to ring weight, thus accounting for the point load penalties associated with the interstage tie. The orbiter attach loads are assumed acting at locations unique to existing rings and, therefore, require the complete addition of two separate frames. Special increments are added to the basic frame sizing for sway braces, doublers, drag links, and fittings, thus completing the total interstage analysis.

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4.9 Structural Weight - Using the basic tank dimensions and the material thickness requirements previously discussed, the basic tank structural weight is calculated. Included in this calculation is a detail assessment of all weld requirements and a fixed value of 0.005 in. is added to all thicknesses to account for material tolerances.

Table 4.9-1 presents the baseline MDAC External Tank Structural Weight Summary and the corresponding computer program output.

TABLE 4.9-1  
ORBITER HO TANK  
PARALLEL BURN-SOLID (2-156 IN.) BOOSTER  
STRUCTURAL WEIGHT SUMMARY

	Completed Analysis Weights
Body Group	[49,030]
Fuel Tank	(22,603)
Aft Bulkhead	3,559
Cylindrical Sidewall	19,044
Oxidizer Tank	( 8,157)
Fwd Bulkhead	337
Sidewall	7,480
Baffles	340
Common Bulkhead	( 4,340)
Booster/Orb/Tank Attach	(12,966)
Nose Fairing	( 464)
Umbilical Panel	( 300)
Tunnel	( 200)

COMPUTER OUTPUT

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BODY GROUP          [ 49202. ]
FWD TANK             ( 8736. )
  FWD BULKHEAD       613.
  CONICAL SECTION    3913.
  CYLINDRICAL SECT.  4209.
  AFT BULKHEAD        0.
INTER TANK SECT.    ( 0. )
AFT TANK             ( 29166. )
  FWD BULKHEAD       6664.
  CYLINDRICAL SECT.  18723.
  AFT BULKHEAD       3778.
ORB/BSTR/TANK ATT.  ( 10100. )
NOSE FAIRING         ( 362. )
UMBILICAL PANEL      ( 300. )
TUNNEL               ( 200. )
BAFFLES-LØX         ( 338. )

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4.10 Miscellaneous Structural Items - Empirical equations and methods are used to calculate the remaining structural items such as forward nose fairing, intertank structure, LOX tank baffles, external lines tunnel, and umbilical panel.

4.11 Induced Environmental Protection - The external tank thermal protection system (TPS) is based on the detail MDAC point design given in Figures 4.11-1 and 4.11-2. Figure 4.11-1 shows the selected thermal protection scheme for the hydrogen and oxygen tank. The 0.375 in. of polyurethane foam insulation was established to meet ground hold and main engine NPSP requirements. The polyurethane foam is applied externally to the liquid hydrogen tank including the fore and aft tank domes in the intertank region. The thermal constraints applied to defining the thermal protection system for the LH<sub>2</sub> tank are based on the thermal stability of the polyurethane foam. The maximum temperature of the surface of the polyurethane foam is limited to 200°F. In the LOX and intertank region, the maximum allowable temperature is 300°F based on the structural properties of aluminum. As shown on the sketch, 0.338 and 0.213 in. of korotherm is required on the noncryogenic nose cap and in the intertank region where the heat sink capacity associated with the -290°F LOX is not available.

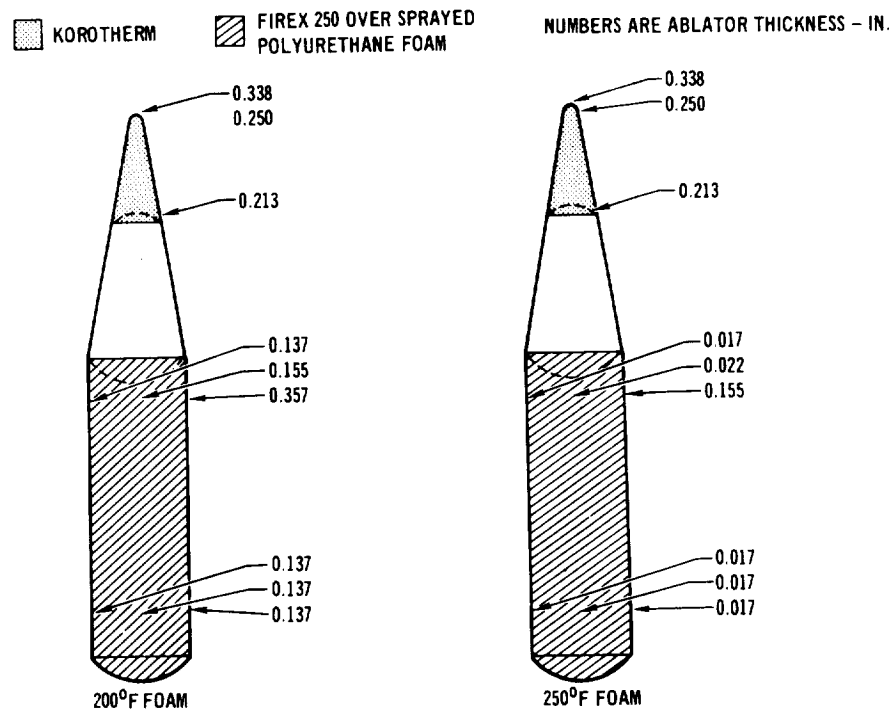
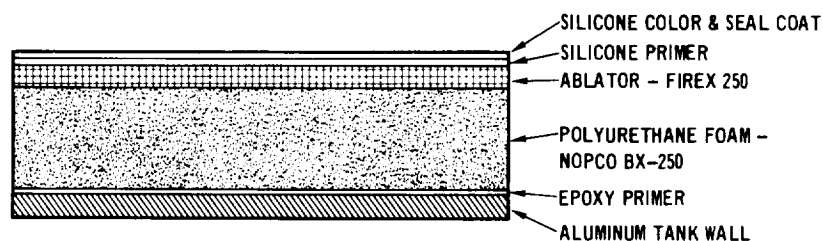


FIGURE 4.11-1 EXTERNAL HO TANK INSULATION  
(Parallel Burn-Solid (2-156 In.))



MATERIAL	DENSITY (LB/FT <sup>3</sup> )	THICKNESS (IN.)	UNIT WT (LB/FT <sup>2</sup> )
1. SILICONE COLOR & SEAL COAT	-	0.006	0.0397
2. SILICONE PRIMER	-	0.001	0.0066
3. ABLATOR - FIREX 250	35	0.137 - 0.357	0.5372 (AVE)
4. POLYURETHANE FOAM - NOPCO BX-250	2	0.375	0.0625
5. EPOXY PRIMER	-	0.001	0.0066
			0.6526 (AVE)

FIGURE 4.11-2 INSULATION MATERIALS BASELINE  
(Parallel Burn – Solid (2-156 IN.)

Figure 4.11-2 defines the cross-sectional geometry of the insulation/TPS concept. The thicknesses and unit weight required for the concept are shown for the LH<sub>2</sub> tank at a 200°F ablator/foam interface temperature.

The basic TPS weight is calculated with input of unit weights for six general regions on the tank surface. The thermal protection system (TPS) is calculated using these unit weights and the basic tank dimensions calculated previously. A fixed 10 percent contingency is added to the total TPS. Table 4.11-1 defines the TPS input data requirements. Figure 4.11-3 shows representative input data for the 200°F ablator/foam interface temperature baseline TPS design.

TABLE 4.11-1  
EXTERNAL TANK TPS INPUT DATA

VARIABLE NAME	DEFINITION	UNITS
NCTPS	NOSE CAP TPS UNIT WEIGHT	LB/FT <sup>2</sup>
UCTPS	UPPER CONE TPS UNIT WEIGHT	LB/FT <sup>2</sup>
LCTPS	LOWER CONE TPS UNIT WEIGHT	LB/FT <sup>2</sup>
CYTPS	CYLINDER (LH2 TANK) TPS UNIT WEIGHT	LB/FT <sup>2</sup>
DMTS	AFT DOME (LH2 TANK) TPS UNIT WEIGHT	LB/FT <sup>2</sup>
INTPS	INTER TANK TPS UNIT WEIGHT	LB/FT <sup>2</sup>

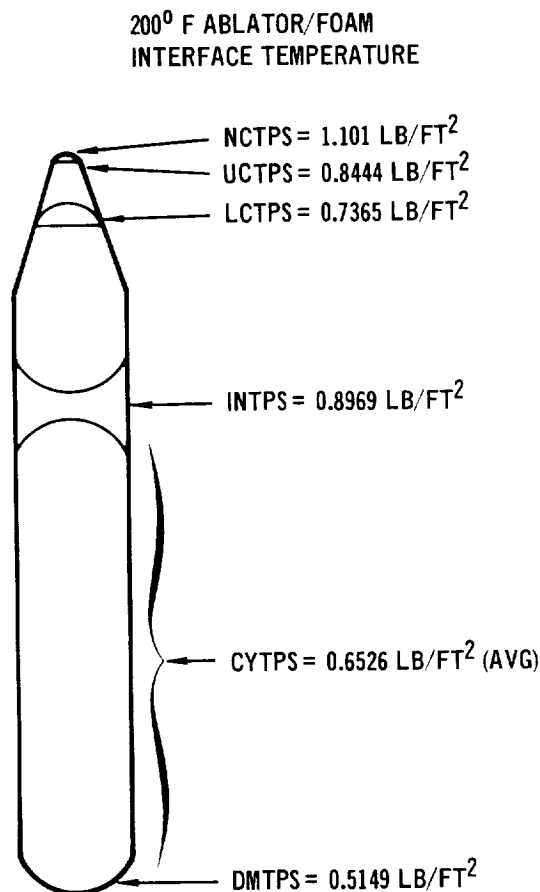


FIGURE 4.11-3 REPRESENTATIVE INPUT DATA  
FOR BASELINE TPS UNIT WEIGHTS

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4.12 Propellant Systems - The basic estimation method for the propellant systems is based on an MDAC detail point design with scaling laws for changes in orbiter engine flow rate, mixture ratio, and tank dimensions. An itemized list of the propulsion system components that make up this baseline system is given in Table 4.12-1 along with the corresponding computer program output. The following is a generalized description of this system.

**TABLE 4.12-1  
EXTERNAL TANK BASELINE PROPELLANT SYSTEMS**

1,530,800 LB PROPELLANT		
<u>LOX FEEDLINE JACKET</u>		
		976 LB
<u>LOX FEED SYSTEM</u>		
°LOX TANK PROPELLANT FEEDLINE	- 1 (17" NOM DIA X 800" LONG)	452
°LOX FEEDLINE FLEX PROVISIONS (3 UNITS EA)	- 2 (17" NOM DIA X 50" LONG)	548
°LOX FEEDLINE DISCONNECT HALF	- 1 (16" NOM DIA X 16" LONG)	255
SUPPORT ALLOWANCE		316
		1,571 LB
<u>LH<sub>2</sub> FEED SYSTEM</u>		
°LH <sub>2</sub> TANK PROPELLANT FEEDLINE	- 1 (16" NOM DIA X 121" LONG)	182
°LH <sub>2</sub> FEEDLINE FLEX PROVISIONS (3 UNITS EA)	- 1 (16" NOM DIA X 48" LONG)	276
°LH <sub>2</sub> FEEDLINE DISCONNECT HALF	- 1 (16" NOM DIA X 16" LONG)	255
SUPPORT ALLOWANCE		178
		891 LB
FEED SYSTEM TOTAL		3,438 LB
<u>LOX VENT SYSTEM</u>		
°VENT & RELIEF VALVES	- 2 (11" NOM DIA X 22" LONG)	224
°GIMBAL ASSEMBLY	- 3 (11" NOM DIA X 11" LONG)	105
°DUCT & MANIFOLD	- 1 (11" NOM DIA X 70" LONG)	122
SUPPORT ALLOWANCE		113
		564 LB
<u>LOX PRESSURIZATION SYSTEM</u>		
°LOX PRESSURIZATION LINE	- 1 (3" NOM DIA X 2,530" LONG)	109
°LOX PRESSURIZATION FLEX PROVISIONS	- 4 (3" DIA X 9" LONG)	24
°LOX PRESSURIZATION DISCONNECT HALF	- 1 (3" DIA X 5" LONG)	12
°LOX PRESSURIZATION DIFFUSER	- 1 (12" DIA X 24" LONG)	40
SUPPORT ALLOWANCE		46
		231 LB
<u>LH<sub>2</sub> VENT SYSTEM</u>		
°VENT & RELIEF VALVES	- 2 (11" NOM DIA X 22" LONG)	224
°DISCONNECT HALF	- 1 (11" NOM DIA X 6" LONG)	32
°MANIFOLD (TEE)	- 1 (11" NOM DIA X 20" LONG)	45
CANNISTER & SUPPORT ALLOWANCE		126
		427 LB
<u>LH<sub>2</sub> PRESSURIZATION SYSTEM</u>		
°LH <sub>2</sub> PRESSURIZATION LINE	- 1 (3" NOM DIA X 1,560" LONG)	66
°LH <sub>2</sub> PRESSURIZATION FLEX PROVISIONS	- 1 (3" NOM DIA X 3" LONG)	12
°LH <sub>2</sub> PRESSURIZATION DISCONNECT HALF	- 1 (3" NOM DIA X 5" LONG)	12
°LH <sub>2</sub> PRESSURIZATION DIFFUSER	- 1 (12" NOM DIA X 24" LONG)	25
SUPPORT ALLOWANCE		29
		144 LB
VENT & PRESS TOTAL		1,366 LB
<u>PNEUMATIC SYSTEM</u>		
°PNEUMATIC LINE	- 1 (1/4" NOM DIA X 3,250" LONG)	24.5
°ACTUATION CONTROL VALVES	- 8 (1/4" NOM DIA X 3" LONG)	8
°PNEUMATIC DISCONNECT HALF	- 1 (1/2" NOM DIA X 3" LONG)	2.5
°CHECK VALVE	- 1 (1/2" NOM DIA X 2" LONG)	2
°PLENUM	- 1 (10" NOM DIA)	8
SUPPORT ALLOWANCE		11
		56 LB
<u>SUMP &amp; VORTEX CONTROL</u>		220
<u>PU SYSTEM</u>		185
TOTAL		5,265 LB

## COMPUTER OUTPUT

PROPELLANT SYSTEMS [	5266.]
FEED SYSTEM	3439.
PRES. AND VENT	1366.
SUMPS & VORTEX CTL	220.
PNEUMATIC & PU SYS	241.

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The HO tank propulsion systems consist of LOX and  $\text{LH}_2$  feed systems, LOX and  $\text{LH}_2$  vent systems, LOX and  $\text{LH}_2$  pressurization systems, pneumatic system, sump and vortex control systems, and PU system.

LOX is supplied to the  $\text{Hi P}_c$  orbiter engines from the tank through one 17-inch diameter feedline which is routed down through the  $\text{LH}_2$  tank and enters the orbiter in the engine area. A jacket is installed around this line to isolate it from the surrounding  $\text{LH}_2$ . For the separate bulkhead designs the LOX line is routed external to the  $\text{LH}_2$  tank and this jacket is not required. The  $\text{LH}_2$  feed system consists of a single 16-inch diameter line from the tank sump to the orbiter. Both LOX and  $\text{LH}_2$  feedlines have flexibility provisions and disconnects.

The LOX vent system consists of an 11-inch diameter vent line running from the forward dome of the LOX tank to two vent valves in the nose cone region. Flexibility provisions are also included.

The LOX pressurization system consists of 2530 inches of 3-inch diameter line which supplies gaseous oxygen (from the engines) from the orbiter interface to the oxygen tank. The line includes flexibility provisions and a disconnect half.

The  $\text{LH}_2$  vent system consists of an 11-inch diameter vent line and two 11-inch valves which are located in a recessed compartment in the wall of the  $\text{LH}_2$  tank. Also included are flexibility provisions and a disconnect half for ground venting.

The  $\text{LH}_2$  pressurization system consists of 1560 inches of 3-inch diameter line for supplying gaseous hydrogen (from the engines) from the orbiter interface to the  $\text{LH}_2$  tank ullage. Included in the system are flexibility provisions, a diffuser, and a disconnect half.

The pneumatic system consists of: 1) 3250 inches of 1/4-inch diameter line; 2) eight actuation control valves for controlling the vent valves; 3) plenum, 4) check valve; and 5) disconnect half.

Both tanks have sumps for minimizing undrainable residuals and controlling vortexing. A PU system with capacitance probes in each tank is used for loading and controlling engine mixture ratio during burn to minimize residuals.

4.13 Deorbit System - The retro rocket propellant is calculated, based on an input required retro delta velocity and ISP. The basic system weight is calculated, using a fixed retro rocket mass fraction of 0.7326, which also includes system mounting and support provisions..

4.14 Miscellaneous Systems - Avionics weight is an input constant. An additional input (MISC) is available for any other desired constant weight.



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4.15 Growth/Uncertainty - Two options are available for calculating growth/uncertainty either as a fixed percent of dry weight or with an input of fixed dry weight which sets growth/uncertainty equal to the difference between the calculated dry weight and the input fixed dry weight.

4.16 Residual Propellants - The previously calculated propellant inventory which is used to establish the total tank volume requirements is also used to determine the specific amount of propellant which is still on board at burnout and is thus used to determine the overall tank mass fraction ( $\frac{\text{Usable Propellant}}{\text{External Tank Gross Weight}}$ ) for performance calculations.

4.17 Simplified Equations Option - Within ESPER the external tank module contains the option of utilizing simplified equations to define the external tank weight rather than the detail analysis.

The purpose of this option is to reduce the computer run time required, as well as, eliminate most of the input variables required to run the detail program. The equations consider external tank usable propellant load, second stage propellant load and tank diameter.

Detail runs of the external tank module were made to parametrically size the NR baseline tank design. The resulting computer output of external tank dry weight was plotted against total propellant load and second stage propellant load for three variations in tank diameter, i.e., 250 in., 300 in., and 350 in. This data was analyzed using a least squares curvefit to determine the three dimensional equation coefficients. The resulting equations are given in Table 4.17-1.

The curvefit results vs the actual computer output are given in Figure 4.17-1.

TABLE 4.17-1  
EXTERNAL TANK CURVEFIT ROUTINE FOR PARAMETRICALLY SIZING  
THE NR BASELINE TANK DESIGN

```
500  RATPRB=PRBPB2/PRBPBT
      IF (RATPRB.LT..50) RATPRB=.50
      CFB=213.777+10.630*RATPRB
      CFA=-31957.6+9444.00*RATPRB
      CFC=.0478364+.0214184*RATPRB
      CFD=-.000104847-.00001602*RATPRB
      CFF=CFC+CFD*DF
      CFE=CFA+CFB*DF
      DRYWT=CFE+CFE*PRBPBT
      IF (PRBPBT.LT.1000000.) DRYWT=DRYWT*(1.11520+.0000001452*PRBPBT)
      IF (PRBPBT.GT.1000000.) DRYWT=DRYWT*(.908317+.0000000567*PRBPBT)
      DRYWT=DRYWT/1.075
      GU=GUP*DRYWT
      DRYWT=DRYWT+GU
      RESIDT=2206.+.001972*PRBPBT
      INERT=DRYWT+RESIDT
```

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REFERENCE: MASS PROPERTIES STATUS REPORT  
NO. SD 72-SH-0120-3  
DATED: 2 DECEMBER 1972

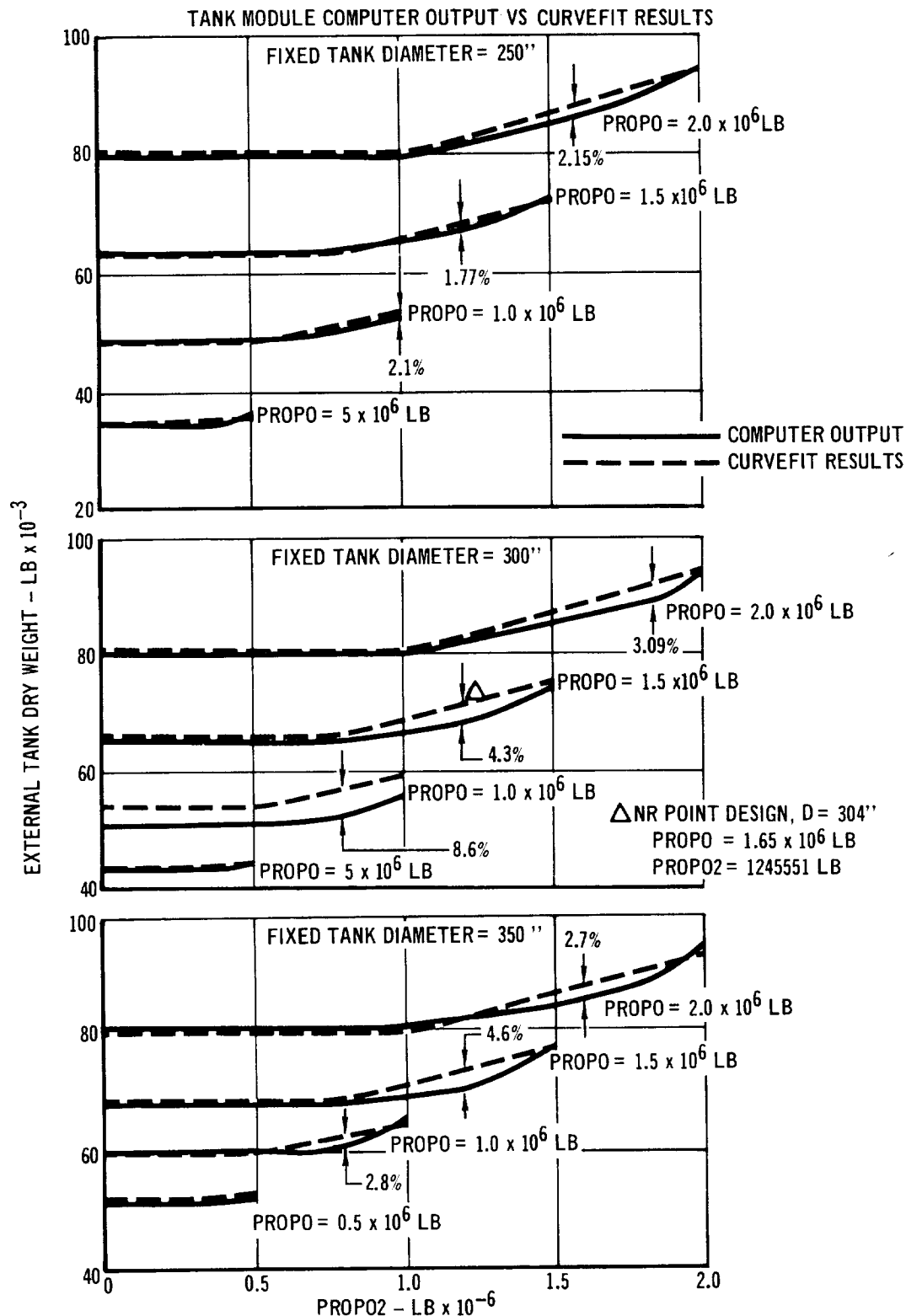


FIGURE 4.17-1 NR BASELINE EXTERNAL TANK DESIGN PARAMETRICALLY SIZED

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4.18 Input Data - The External Tank Module complete input data nomenclature is given in Table 4.18-1. Three sample data files for the three baseline tank designs previously discussed are given in Table 4.18-2. Figure 4.18-1 presents recommended limits for tank sizing input data.

TABLE 4.18-1  
EXTERNAL TANK INPUT DATA NOMENCLATURE

VARIABLE NAME	DEFINITION	UNITS
INPUT PARAMETERS		
PROPO	Useable Propellant Load	LB
PROPO2	Useable Propellant Required for 2nd Stage Burn	LB
MRI	Mixture Ratio, Oxidizer/Fuel	ND
NR, ND	Nose Cap Radius and/or Nose Diameter	IN.
HRI	Ratio of Blkhd Height to Blkhd Hemispherical Radius $\sim$ HR/R	ND
THETA	$\Theta$ - Forward Cone Angle	DEG
LA	Load Allowance (1 + Dec. %)	ND
UPERO	Percent Oxidizer Ullage (1 + Dec. %)	ND
UPERF	Percent Fuel Ullage (1 + Dec. %)	ND
OPRES, OUPRES	Oxidizer Pressure Operating, Ullage	LB/IN <sup>2</sup>
FOPRES, FUPRES	Fuel Pressure Operating, Ullage	LB/IN <sup>2</sup>
THRO, ISPOT	Orbiter Eng. Thrust, ISP for Flow Required	LB SEC
BLKHD	Ind. 1 - Common; 2 - Separate; 3 = Alternate	-
BX	Dummy Ind. to Test Series Burn Pt. Des.	-
LCON	Clearance Between Bulkheads	IN.
K	Structural Space Allowance	IN.
HBIAS	Optional Fixed Fuel Bias	LB
GEOMETRY SOLUTION		
INPUT OPTIONS		
LD	Required L/D - Output is Resultant Length and Diameter	ND
LF	Required Fixed Length - Output is Resultant Diameter	IN.
DF	Required Fixed Diameter - Output is Resultant Length	IN.
INPUT REQUIRED FOR INITIALIZATION		
DI	Initial Guess at Tank Diameter	IN.
LI	Initial Guess at Tank Length	IN.
HHI	Initial Guess at Fuel Tank Length	IN.

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TABLE 4.18-1  
EXTERNAL TANK INPUT DATA NOMENCLATURE (Continued)

VARIABLE NAME	DEFINITION	UNITS
STRUCTURAL MATERIAL PROPERTIES		
RHO	Material Density	LB/IN <sup>3</sup>
FTU	Material Ult. Tensile Strength	LB/IN <sup>2</sup>
E	Material Modulus of Elasticity	LB/IN <sup>2</sup>
FS	Factor of Safety	ND
TMIN	Material Minimum Gauge	IN.
LOADS PARAMETERS		
THBSL	Total Booster S.L. Thrust	LB.
NN	Number of Booster Engines	ND
CANT	Booster Thrust Cant Angle	DEG
BGLOW	Booster Gross Liftoff Weight	LB
R1, R2, RL	Orbiter Interstage Reaction Loads from Orbiter Module	LB
NXL	Liftoff Vertical Load Factor	ND
NXS	Staging Vertical Load Factor	ND
IND. ENVIRON. PROT.		
NCTPS	Nose Cap TPS Unit Weight	LB/FT <sup>2</sup>
UCTPS	Upper Cone TPS Unit Weight	LB/FT <sup>2</sup>
LCTPS	Lower Cone TPS Unit Weight	LB/FT <sup>2</sup>
CYTPS	Cylinder (Fuel Tank) TPS Unit Weight	LB/FT <sup>2</sup>
DMTPS	Aft Dome (Fuel Tank) TPS Unit Weight	LB/FT <sup>2</sup>
INTPS	Inter Tank TPS Unit Weight	LB/FT <sup>2</sup>
OTHER PARAMETERS		
RETDV	Retro Delta Velocity	FT/SEC
RETISP	Retro Rocket ISP	SEC
AVION	Constant Inputted for the Avionics System Weight	LB
MISC	Additional Input Available for any Desired Constant Weight Increment	LB
GUP	Growth/Uncertainty (Dec. %)	ND
FIXDWT	Optional Fixed Dry Weight if Greater than Zero Growth/Uncertainty is Calculated as Difference Between Calculated Dry Weight and Fixed Dry Weight	LB
AFT	Ind. 0 = LOX FWD; 1 = LOX AFT	ND

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TABLE 4.18-2  
SAMPLE DATA FILES

```

EDIT TNKDAT          BASELINE MDAC COMMON BULKHEAD DESIGN
* TY0-20
  1.000 PROPO=1530800.,MRI=6.,THETA=20.,NR=25.,UPERO=1.02,LA=1.01
  2.000 THRO=1410000.,ISPOT=455.,FOPRES=40.,OPRES=30.,FUPRES=40.
  3.000 OUPRES=18.,HHI=100.,LCON=0.,BLKHD=1.,BX=1.,K=0.
  3.500 UPERF=1.02,HBIAS=0.,HRI=.5
  4.000 LD=4.98235,DI=0.,LI=1000.,LF=0.,DF=0.
  5.000 GUP=.02,FIWDWT=0.,CANT=15.,AFT=0.,RHO=.102,FTU=64000.
  6.000 E=10500000.,NN=2.,THBSL=4802000.,BGLW=2258300.
  7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
  8.000 INTPS=.8969,R1=194500.,R2=434800.,RL=1654000.,NYL=1.4
  9.000 NXS=3.0,PROPO2=1155220.,ND=0.,FS=1.4,TMIN=.025,AVION=274.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  11.000 LD=0.,DI=100.,LF=1694.*
  12.000 DF=340.,DI=0.*
--EOF HIT AFTER 12.

*                               MDAC SEPARATE BULKHEAD DESIGN
EDIT TNKDAT2
* TY0-20
  1.000 PROPO=942100.,MRI=6.,THETA=15.,NR=33.,UPERO=1.02,LA=1.01
  2.000 THRO=1410000.,ISPOT=455.,FOPRES=70.,OPRES=30.,FUPRES=40.
  3.000 OUPRES=18.,HHI=100.,LCON=20.,BLKHD=2.,BX=0.,K=0.
  3.500 UPERF=1.02,HBIAS=0.,HRI=.5
  4.000 LD=4.68152,LI=1000.,LF=0.,DF=0.
  5.000 GUP=.062,FIWDWT=0.,CANT=0.,AFT=0.,RHO=.102,FTU=64000.
  6.000 E=10500000.,NN=2.,THBSL=6495276.,BGLW=3960187.
  7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
  8.000 INTPS=.8969,R1=194500.,R2=434800.,RL=1654000.,NYL=1.4
  9.000 NXS=3.0,PROPO2=942100.,ND=0.,FS=1.4,TMIN=.025,AVION=345.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  11.000 LF=1470.,LI=0.,LD=0.*
  12.000 DF=314.,LI=1000.,LF=0.*
--EOF HIT AFTER 12.

*                               NR BASELINE DESIGN (2 DEC 1972)
EDIT NRINK
* TY0-20
  1.000 PROPO=1650000.,MRI=6.,THETA=30.,ND=41.,UPERO=1.0287,LA=1.01
  2.000 THRO=1410000.,ISPOT=455.2,FOPRES=37.,OPRES=22.,FUPRES=35.
  3.000 OUPRES=20.,HHI=100.,LCON=30.,BLKHD=3.,BX=1.,K=.15
  3.500 UPERF=1.03,HBIAS=1500.,HRI=.6496
  4.000 LD=0.,DI=0.,LI=1000.,LF=0.,DF=304.
  5.000 GUP=.075,FIWDWT=0.,CANT=8.5,AFT=0.,RHO=.102,FTU=64000.
  6.000 E=10500000.,NN=2.,THBSL=7834000.,BGLW=3276114.
  7.000 NCTPS=1.101,UCTPS=.8444,LCTPS=.7365,CYTPS=.6526,DMTPS=.5149
  8.000 INTPS=.8969,R1=141000.,R2=469000.,RL=1654000.,NYL=1.4
  9.000 NXS=3.3,PROPO2=1245551.,NR=0.,FS=1.4,TMIN=.025,AVION=800.
  10.000 MISC=0.,RETDV=200.,RETISP=260.*
  12.000 DF=0.,LF=2152.*
  13.000 LD=7.11184,LF=0.*
--EOF HIT AFTER 13.

```

\*

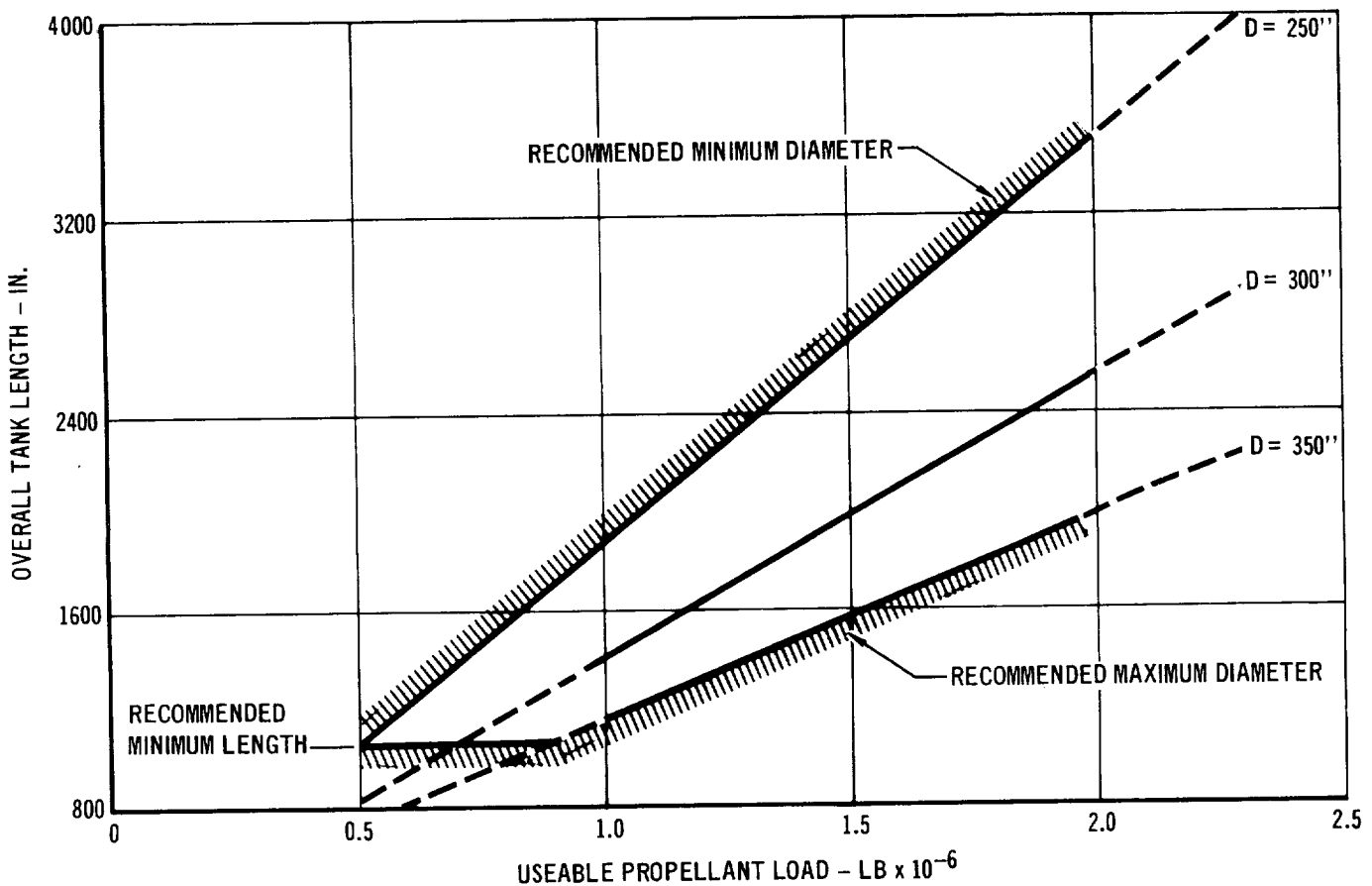


FIGURE 4.18-1 EXTERNAL TANK OVERALL LENGTH vs USEABLE PROPELLANT LOAD  
MR = 6. LOX/LH<sub>2</sub> – LOX Fwd Separate Bulkhead Design

4.19 Output – Computer output from the three input data files of Table 4-14 are given in Tables 4.19-1, 4.19-2 and 4.19-5 through 4.19-8. The NR baseline tank output of Tables 4.19-1 and 4.19-2 corresponds to the point design weight summary given in Table 4.19-3. The computer output dry weight for this tank is within 1.5 percent of the reported weight given in Table 4.19-3. Table 4.19-4 shows the MDAC point design weight analysis and the corresponding computer output. This data indicates program accuracy of considerably better than 1 percent.

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ITEM	LOX	LH2
PROPELLANT WEIGHT-LB.		
ASCENT (INCLUDES FPR)	1414285.	235714.
START PROPELLANT	7411.	1440.
SHUTDOWN ADJUSTMENT	150.	87.
FEEDLINE RESIDUAL	918.	254.
CHILLDOWN RESIDUAL	134.	6.
ENGINE RESIDUAL	1072.	75.
PU BIAS	0.	1500.
TANK UNDRAINABLE	300.	100.
PRESSURANT	2084.	750.
	-----	-----
NOMINAL LOAD	1426349.	239926.
LOADING ALLOWANCE	14264.	2399.
	-----	-----
MAXIMUM LOAD	1440612.	242325.
PROPELLANT BELOW TANK	- 20351.	- 335.
	-----	-----
MAXIMUM LOAD IN TANK	1420261.	241990.
PROPELLANT VOLUME-FT3		
PROPELLANT VOLUME IN TANK	20004.	54998.
TANK VOLUME FOR FLUIDS	20598.	56648.
VOL. DISPLACED BY LOX FEEDLINE	0.	0.
	-----	-----
TOTAL TANK VOLUME	20598.	56648.

[illegible]

LOX TANK VOLUME= 20598. FT3    LH2 TANK VOLUME= 56648. FT3

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TABLE 4.19-2  
NR BASELINE SEPARATE BULKHEAD  
(Fixed Diameter Case)

EXTERNAL TANK WEIGHT SUMMARY			
ALTERNATE FWD SECTION(WITHOUT NOSE FAIRING)			
		WEIGHT	WEIGHT
		-LB.	-LB.
BODY GROUP	[ 51840. ]	IND. ENVIRN. PROT. [	7878. ]
FWD TANK	( 12391. )	NOSE FAIRING	0.
FWD BULKHEAD	14.	FWD CONE & CYL.	0.
CONICAL SECTION	2784.	INTER TANK	1687.
CYLINDRICAL SECT.	5346.	AFT CYL & DOME	6191.
AFT BULKHEAD	4247.		
INTER TANK SECT.	( 5264. )	PROPELLANT SYSTEMS [	5118. ]
AFT TANK	( 24581. )	FEED SYSTEM	2914.
FWD BULKHEAD	2579.	PRES. AND VENT	1746.
CYLINDRICAL SECT.	19027.	SUMPS & VORTEX CTL	220.
AFT BULKHEAD	2975.	PNEUMATIC & PU SYS	237.
ORB/BSTR/TANK ATT.(	8168. )		
NOSE FAIRING	( 0. )	AVIONICS	[ 800. ]
UMBILICAL PANEL	( 300. )	DEORBIT SYSTEM	[ 2535. ]
TUNNEL	( 644. )	MISCELLANEOUS	[ 0. ]
BAFFLES-LOX	( 491. )		
		SUBTOTAL DRY WEIGHT	68170.

SUBTOTAL DRY WEIGHT 68170.

GROWTH/UNCERTAINTY [ 5113. ]

-----  
DRY WEIGHT 73283.

RESIDUAL PROPELLANT [ 5461. ]  
TANK UNDRAINABLE 400.  
FEEDLINE TRAPPED 307.  
PRESSURANT 3254.  
PU BIAS 1500.

-----  
INERT WEIGHT 78744.

USABLE PROPELLANT [ 1650000. ]

-----  
TOTAL GROSS WEIGHT 1728743.

LAMBDA=WPROP /WGROSS= .9545



TABLE 4.19-3  
NR POINT DESIGN WEIGHT SUMMARY

ITEM	REFERENCE: 2 DECEMBER 1972
	MASS PROPERTIES STATUS REPORT WEIGHT -LB.
BODY GROUP	48,320
IND. ENVIR. PROT.	7,910
PROPULSION, ASCENT	7,090
PROPULSION, AUX.	3,100
AVIONICS	800
GROWTH	<u>5,040</u>
SUBTOTAL (DRY WT)	72,260
RESIDUAL FLUIDS	<u>9,580</u>
SUBTOTAL (INERT WT)	81,840
PROPELLANT - ASCENT	<u>1,650,000</u>
TOTAL WEIGHT -	1,731,840
LAMBDA = 0.9527	

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TABLE 4.19-4  
ORBITER HO TANK  
PARALLEL BURN-SOLID (2-156'') BOOSTER  
WEIGHT SUMMARY

	COMPLETED ANALYSIS WTS.		COMPLETED ANALYSIS WTS.
BODY GROUP	[49,030]	ELECT/INSTRUMENTATION	[ 274]
FUEL TANK	(22,603)	BATTERIES	20
AFT BULKHEAD	3,559	POWER DISTRIBUTION	20
CYLINDRICAL SIDEWALL	19,044	EBW FIRING UNITS	29
OXIDIZER TANK	( 8,157)	PU ELECTRONICS	10
FWD BULKHEAD	337	RANGE SAFETY	30
SIDEWALL	7,480	INSTRUMENTATION	17
BAFFLES	340	COAX AND WIRING	148
COMMON BULKHEAD	( 4,340)	DEORBIT SYSTEM	[ 2,170]
BOOSTER/ORB/TANK ATTACH	(12,966)	GROWTH/UNCERTAINTY (2%)	[ 1,265]
NOSE FAIRING	( 464)	DRY WEIGHT	64,550
UMBILICAL PANEL	( 300)	RESIDUAL PROPELLANTS	[ 3,854]
TUNNEL	( 200)	TANK UNDRAINABLES	100
INDUCED ENVIRONMENT PROTECT.	[ 6,546]	FRED LINE TRAPPED	317
ABLATOR	5,344	PRESSURANT	2,890
FOAM	612	PU BIAS	547
PRIMER, PAINT AND SEALER	590		
PROPELLANT SYSTEMS	[ 5,265]	INERT WEIGHT	68,404
FEED SYSTEM	3,438	USABLE PROPELLANT	[1,530,800]
PRESS. AND VENT	1,366	TOTAL GROSS WEIGHT	1,599,204
SUMPS & VORTEX CONTROL	220		
PU SYSTEMS	185		
PNEUMATICS	56		
		$\lambda = \frac{W_{PRDP}}{W_{GROSS}} =$	0.9572

Computer Output (Fixed Length)

EXTERNAL TANK WEIGHT SUMMARY COMMON BULKHEAD-LOX FWD			
	WEIGHT -LB.		WEIGHT -LB.
BODY GROUP	( 49203. )	IND. ENVIRN. PROT. (	6416. )
FWD TANK	( 8747. )	NOSE FAIRING	650.
FWD BULKHEAD	612.	FWD CONE & CYL.	0.
CONICAL SECTION	3904.	INTER TANK	0.
CYLINDRICAL SECT.	4230.	AFT CYL & DOME	5766.
AFT BULKHEAD	0.		
INTER TANK SECT. (	0. )	PROPELLANT SYSTEMS (	5269. )
AFT TANK	( 29157. )	FEED SYSTEM	3442.
FWD BULKHEAD	6658.	PRES. AND VENT	1366.
CYLINDRICAL SECT.	18729.	SUMPS & VORTEX CTL	220.
AFT BULKHEAD	3771.	PNEUMATIC & PU SYS	241.
ORB/OSTR/TANK ATT.(	10098. )		
NOSE FAIRING	( 362. )	AVIONICS	( 274. )
UMBILICAL PANEL	( 300. )	DEORBIT SYSTEM	( 2208. )
TUNNEL	( 200. )	MISCELLANEOUS	( 0. )
BAFFLES-LOX	( 339. )		
		SUBTOTAL DRY WEIGHT	63370.
		SUBTOTAL DRY WEIGHT	63370.
		GROWTH/UNCERTAINTY (	1267. )
		DRY WEIGHT	64637.
		RESIDUAL PROPELLANT	3853. )
		TANK UNDRAINABLE	100.
		FEEDLINE TRAPPED	317.
		PRESSURANT	2890.
		PU BIAS	547.
		INERT WEIGHT	68490.
		USABLE PROPELLANT (	1530800. )
		TOTAL GROSS WEIGHT	1599289.
		LAMBDA=WPROP/WGROSS=	.9572

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ITEM	LOX	LH2
PROPELLANT WEIGHT-LB.		
ASCENT (INCLUDES FPR)	1312114.	218686.
START PROPELLANT	7414.	1441.
SHUTDOWN ADJUSTMENT	150.	87.
FEEDLINE RESIDUAL	918.	284.
CHILLDOWN RESIDUAL	134.	6.
ENGINE RESIDUAL	1072.	75.
PU BIAS	0.	547.
TANK UNDRAINABLE	0.	100.
PRESSURANT	1740.	795.
	-----	-----
NOMINAL LOAD	1323537.	222020.
LOADING ALLOWANCE	13236.	2220.
	-----	-----
MAXIMUM LOAD	1336772.	224240.
PROPELLANT BELOW TANK	- 13082.	- 365.
	-----	-----
MAXIMUM LOAD IN TANK	1323690.	223875.
PROPELLANT VOLUME-FT3		
PROPELLANT VOLUME IN TANK	18644.	50881.
TANK VOLUME FOR FLUIDS	19016.	51898.
VOL. DISPLACED BY LOX FEEDLINE	0.	227.
	-----	-----
TOTAL TANK VOLUME	19016.	52125.

```

-----X X X X X X X X X X X X X X X X X-----
THETA X-----X                                     X .
      .X X                      X                     X .
NR..X ND X..OR OD            X                        R...X D
      ...X X                      X                    X .
      .. . X-----X                                   X. .
      .. .HOR. X X X X X X X X X X X X X X X X X X X X X .-----
HN-- ..-- .HCO.              .HR.
      ..--HC-.-HO-.-HH-----HH-----HR.
      ..--L=HN+HC+HO+HH+HR-----

```

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TABLE 4.19-6  
MDAC BASELINE DESIGN  
(Fixed L/D Case)

EXTERNAL TANK WEIGHT SUMMARY  
COMMON BULKHEAD-LOX FWD

	WEIGHT -LB.		WEIGHT -LB.
BODY GROUP	[ 49219. ]	IND. ENVIRN. PROT.	[ 6414. ]
FWD TANK	( 8747. )	NOSE FAIRING	651.
FWD BULKHEAD	613.	FWD CONE & CYL.	0.
CONICAL SECTION	3913.	INTER TANK	0.
CYLINDRICAL SECT.	4221.	AFT CYL & DOME	5763.
AFT BULKHEAD	0.		
INTER TANK SECT.	( 0. )	PROPELLANT SYSTEMS	[ 5266. ]
AFT TANK	( 29172. )	FEED SYSTEM	3439.
FWD BULKHEAD	6671.	PRES. AND VENT	1366.
CYLINDRICAL SECT.	18723.	SUMPS & VORTEX CTL	220.
AFT BULKHEAD	3778.	PNEUMATIC & PU SYS	241.
ORB/BSTR/TANK ATT.	( 10100. )		
NOSE FAIRING	( 362. )	AVIONICS	[ 274. ]
UMBILICAL PANEL	( 300. )	DEORBIT SYSTEM	[ 2208. ]
TUNNEL	( 200. )	MISCELLANEOUS	[ 0. ]
BAFFLES-LOX	( 338. )		
		SUBTOTAL DRY WEIGHT	63382.

SUBTOTAL DRY WEIGHT 63382.

GROWTH/UNCERTAINTY [ 1268. ]

-----  
DRY WEIGHT 64650.

RESIDUAL PROPELLANT [ 3853. ]

TANK UNDRAINABLE 100.

FEEDLINE TRAPPED 317.

PRESSURANT 2890.

PU BIAS 547.

-----  
INERT WEIGHT 68503.

USABLE PROPELLANT [ 1530800. ]

-----  
TOTAL GROSS WEIGHT 1599302.

LAMBDA=WPROP/WGROSS= .9572

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ITEM	LOX	LH2
PROPELLANT WEIGHT-LB.		
ASCENT (INCLUDES FPR)	80 75 14.	13 45 86.
START PROPELLANT	10 15.	372.
SHUTDOWN ADJUSTMENT	150.	87.
FEEDLINE RESIDUAL	918.	256.
CHILLDOWN RESIDUAL	272.	19.
ENGINE RESIDUAL	1072.	75.
PU BIAS	0.	336.
TANK UNDRAINABLE	300.	100.
PRESSURANT	1071.	489.
	-----	-----
NOMINAL LOAD	812312.	136321.
LOADING ALLOWANCE	8123.	1363.
	-----	-----
MAXIMUM LOAD	820435.	137684.
PROPELLANT BELOW TANK	- 12538.	- 351.
	-----	-----
MAXIMUM LOAD IN TANK	807896.	137333.
PROPELLANT VOLUME-FT3		
PROPELLANT VOLUME IN TANK	11379.	31212.
TANK VOLUME FOR FLUIDS	11606.	31836.
VOL. DISPLACED BY LOX FEEDLINE	0.	0.
	-----	-----
TOTAL TANK VOLUME	11606.	31836.

```

-----X X X X X X X X X X X X X X X X X X-----
THETA X-----X X
.X X . X X
NR..X ND X..OR OD ...X X...LCON R...X D
...X X . X X
. . X-----X X
. . .HOR. X X X X X X X X X X X X X X X X X X .-----
HN--.---HCO. .HR.
.---HC---HO---.-----HH-----HR.
-----L=HN+HC+HO+HR+LCON+HH+HR-----

```

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TABLE 4.19-8  
MDAC BASELINE DESIGN  
(Fixed Length Case)

EXTERNAL TANK WEIGHT SUMMARY  
SEPARATE BULKHEAD-LOX FWD  
WEIGHT  
-LB.

WEIGHT  
-LB.

BODY GROUP	( 50505. )	IND. ENVIRN. PROT. [	5330. ]
FWD TANK	( 10665. )	NOSE FAIRING	536.
FWD BULKHEAD	357.	FWD CONE & CYL.	0.
CONICAL SECTION	4608.	INTER TANK	1298.
CYLINDRICAL SECT.	1662.	AFT CYL & DOME	3496.
AFT BULKHEAD	4037.		
INTER TANK SECT. (	4764. )	PROPELLANT SYSTEMS [	4518. ]
AFT TANK	( 26590. )	FEED SYSTEM	2475.
FWD BULKHEAD	3704.	PRES. AND VENT	1594.
CYLINDRICAL SECT.	18970.	SUMPS & VORTEX CTL	220.
AFT BULKHEAD	3917.	PNEUMATIC & PU SYS	229.
ORB/BSTR/TANK ATT.(	7179. )		
NOSE FAIRING	( 292. )	AVIONICS	[ 345. ]
UMBILICAL PANEL	( 300. )	DEORBIT SYSTEM	[ 2246. ]
TUNNEL	( 446. )	MISCELLANEOUS	[ 0. ]
BAFFLES-LOX	( 267. )		
		SUBTOTAL DRY WEIGHT	62943.

SUBTOTAL DRY WEIGHT 62943.

GROWTH/UNCERTAINTY [ 3902. ]

-----  
DRY WEIGHT 66846.

RESIDUAL PROPELLANT [ 2903. ]  
TANK UNDRAINABLE 400.  
FEEDLINE TRAPPED 307.  
PRESSURANT 1859.  
PU BIAS 336.

-----  
INERT WEIGHT 69749.

USABLE PROPELLANT [ 942100. ]

-----  
TOTAL GROSS WEIGHT 1011849.

LAMBDA=WPROP/WGROSS= .9311

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4.20 Program Listing - The following pages contain the complete External Tank Module FORTRAN program listing (Table 4.20-1).

TABLE 4.20-1  
PROGRAM LISTING

```

12:03 FEB 24, 1973 ID=P15P
JOB K5511, WTSIZ
LIMIT (HORDER), (ACCOUNT), (C9,9), (T1,3), (L9,100), (P9,200), (T9,500), (9T,0)
PCL
COPY TKSIZ3 TO LP(K,NC)
1 - .500 $FLAGB9=TKSIZ39
2 - 1.000 $FIXED
3 - 2.000 C THIS PROGRAM COMPUTES EXTERNAL (L9X/LH2) TANK DIMENSIONS
4 - 3.000 C AND WEIGHT KNOWING MIXTURE RATIO, USEABLE PROPELLANT
5 - 4.000 C LOAD AND EITHER REQUIRED TANK L/D, LENGTH OR DIAMETER.
6 - 5.000 IMPLICIT REAL(A-Z)
7 - 5.500 INTEGER I
8 - 6.000 DIMENSION HFX(9),
9 - 7.000 HFX(9), H9X(9), TF(9), T9(9), MF(9), M9(9),
10 - 8.000 ASHCT(9), WLOF(9), WLD9(9)
11 - 9.000 NAMELIST
12 - 10.000 X, DI, LI, LD, NR, ND, THETA, WHI, PR9PR, MRI, UPER9, LA, F9PRES, 9PRES
13 - 11.000 X, FUPRES, 9UPRES, THR9, ISP9T, LF, DF, LC9N, BLK9D, BX, K, JPERF,
14 - 12.000 X, RIAS, FS, NXL, NXS, FTU, E, PR9P92, RH9, TMIN, R2, R1, RL,
15 - 13.000 X, NCTPS, JCTPS, LCTPS, CYTPS, INTPS, DMTPS, FIXDWT, GUP,
16 - 14.000 X, RET9V, RETISP, AVIS9, MISC, AFT, TH9SL, NN, CANT, BGL9W, HRI
17 - 15.000 30 INPUT(1)
18 - 17.000 IF(AFT.NE.0.) G9 TO 11
19 - 18.000 G9 TO 12
20 - 19.500 C SET L9X AFT (INVERT MR & SWITCH DENSITIES)
21 - 19.000 11 MR=1./MRI
22 - 19.100 XFUP9=9UPRES
23 - 19.200 XF99=9PRES
24 - 19.300 X9UP9=FUPRES
25 - 19.400 X9PR=F9PRES
26 - 19.500 XPER9=JPERF
27 - 19.600 XPERF=UPER9
28 - 20.000 F9DEN=71.
29 - 21.000 9DEN=4.4
30 - 21.500 G9 TO 13
31 - 21.600 C BASELINE L9X FORWARD
32 - 22.000 12 F9DEN=4.4
33 - 22.000 9DEN=71.
34 - 23.500 MR=MRI
35 - 23.600 C INITIALIZE DIMENSIONS OF FIXED DIAMETER,
36 - 23.700 C LF=FIXED LENGTH, LD=FIXED L/D, LI, WHI ARE
37 - 23.800 C INITIAL GUESSES
38 - 24.000 13 LH=WHI
39 - 24.100 FUEL=PR9PR/(1.+MR)
40 - 24.200 9XID=FUEL*MR
41 - 24.300 IF(LF.EQ.0.) G9 TO 5
42 - 24.400 TV9L=FUEL/F9DEN+9XID/9DEN
43 - 24.500 D=((TV9L*1729.)/(1.7854*LF))**.5
44 - 26.000 5 IF(DF.GT.0.) D=DF
45 - 27.000 L=LI
46 - 28.000 IF(LF.GT.0.) L=LF
47 - 29.000 10 IF(LD.GT.0.) D=L/LD
48 - 30.000 D=D-2.**4
49 - 30.500 C CALCULATE DEPENDENT DIMENSIONS, THETA IS FWD
50 - 30.600 C CRNF ANGLE INPUTTED IN DEGREES
51 - 31.000 15 IF(9L<9T.GT.2.) G9 TO 16
52 - 32.000 ND=2.**NR*CSS(THETA/57.2958)
53 - 33.000 16 HC=(1.5*D-.5*ND)/TAN(THETA/57.2958)
54 - 34.000 R=D/3.**.5
55 - 35.000 HR=HRI*R

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PROGRAM LISTING (Continued)

56 -	34.000	IF(BLK<40.0) G9 T9 17
57 -	37.000	HC9=40.1364/SIN(THETA/57.2958)
58 -	38.000	SD=2.2*HC9*TAN(THETA/57.2958)
59 -	39.000	HR=30/3.14159
60 -	40.000	HRR=.5*HR
61 -	41.000	HN=NR-.5*(4.1*NR**2-ND**2)**.5
62 -	41.500 C	CALCULATE DEPENDENT VOLUMES
63 -	42.000	VOLF=.261*HC9*(D**2+D*SD+SD**2)
64 -	43.000	V9L3=1.0472*HR**2*(3.14159-HR)
65 -	44.000	G9 T9 18
66 -	45.000	17 VOLF=.2618*HC9*(D**2+D*ND+ND**2)
67 -	46.000	18 V9LA=1.0472*HR**2*(3.14159-HR)
68 -	47.000	V9LC=.7854*D**2*HR-V9LA
69 -	48.000	IF(BLK<40.0) V9LC=V9LA
70 -	49.000	V9LD=V9LA
71 -	49.500 C	CALCULATE PROPELLANT INVENTORY
72 -	50.000	9FL9W=THRO/ISP9T
73 -	51.000	9FL9WX=9FL9W/(1.1*MR)
74 -	52.000	9FL9WY=9FL9W*MR/(1.1*MR)
75 -	53.500 C	FUEL INVENTORY
76 -	54.000	FSTART=3.255*9FL9WX
77 -	55.000	IF(RX.NE.1.0) FSTART=.84*9FL9WX
78 -	56.000	F9HJT=.1965*9FL9WX
79 -	57.000	F9EDF=.00189*D*9FL9WX
80 -	58.000	F9HILL=.01355*9FL9WX
81 -	59.000	IF(RX.NE.1.0) F9HILL=.0435*9FL9WX
82 -	60.000	F9ENG=.16941*9FL9WX
83 -	61.000	F9IAS=.0025*FUEL
84 -	62.000	IF(4BIAS>GT.0.1) F9IAS=HBIAS
85 -	63.000	F9DRAIN=100.
86 -	64.000	F9EL9W=F9EDF+F9HILL+F9ENG
87 -	65.000	DISPVF=.0000952*(4H-HR)*9FL9WY
88 -	66.000	IF(BLK<40.0) DISPVF=0.
89 -	67.100	IF(AFT>EQ.0.1) G9 T9 35
90 -	67.200	UPERF=XPERF
91 -	67.300	F9PRES=XF9PR
92 -	67.400	F9PRES=XF9PR
93 -	67.500	F9PRESS=.001324*FUEL*F9PRES/18.
94 -	67.600	F9ES=.00497*FUEL*(UPERF+LA-2.0)*F9PRES/30.
95 -	67.700	G9 T9 34
96 -	68.000	35 F9PRESS=.002635*FUEL*F9PRES/40.
97 -	69.000	F9ES=.02667*FUEL*(UPERF+LA-2.0)*F9PRES/40.
98 -	69.500 C	NOMINAL FUEL LOAD
99 -	70.000	36 N9VFUL=FUEL+FSTART+F9HJT+F9EDF+F9HILL+F9ENG+F9IAS+F9DRAIN
100 -	71.000	5+F9PRESS
101 -	71.500 C	FUEL LOADING ALLOWANCE
102 -	72.000	FALL9W=N9VFUL*(LA-1.0)
103 -	73.000	MAXFUL=N9VFUL+FALL9W
104 -	73.500 C	MAXIMUM FUEL IN TANK
105 -	74.000	MAXFIT=MAXFUL-F9EL9W
106 -	74.500 C	FUEL VOLUME
107 -	75.000	F9V9L=MAXFIT/F9EN
108 -	75.500 C	ADD FUEL ULLAGE VOLUME
109 -	76.000	TFVFL=F9V9L*UPERF
110 -	76.500 C	ADD V9L DISPLACED BY LOX LINE IF COMMON BLKHD DES
111 -	77.000	TFVIT=TFVFL+DISPVF
112 -	77.500 C	OXYGEN INVENTORY
113 -	78.000	9START=2.7912*9FL9WY
114 -	79.000	IF(RX.NE.1.0) 9START=.382*9FL9WY
115 -	80.000	9SHJT=.0565*9FL9WY
116 -	81.000	F9EDF=.3456*9FL9WY



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PROGRAM LISTING (Continued)

117 -	32.000		9CHILL=.05044*9FL9WY
118 -	33.000		IF(RY.NE.1.0) 9CHILL=.1025*9FL9WY
119 -	34.000		9ENG=.40358*9FL9WY
120 -	35.000		9DRAIN=0.
121 -	36.000		IF(3L<HD*GT.1.) 9DRAIN=300.
122 -	37.000		9LINE=.0046*(HH-HR)*9FL9WY
123 -	38.000		IF(3L<HD*GT.1.0) 9LINE=.0046*(HH+.5*D+LCBN)*9FL9WY
124 -	39.000		9FEL9W=9LINE+FEED9+9CHILL+9ENG
125 -	39.100		IF(AFT.EQ.0.) G9 TO 37
126 -	39.200		JPER9=XPER9
127 -	39.300		9UPRES=X9UPR
128 -	39.400		9PRES=X9PR
129 -	39.500		9PRESS=.003635*9XID*9JPRES/40.
130 -	39.600		9RES=.02667*9XID*(JPER9+LA-2.)*9PRES/40.
131 -	39.700		G9 TO 38
132 -	30.000	37	9PRESS=.001326*9XID*9JPRES/18.
133 -	31.000		9RES=.00457*9XID*(JPER9+LA-2.)*9PRES/30.
134 -	31.500	C	NOMINAL 9XYGEN LOAD
135 -	32.000	38	NOM9XL=9XID*9START+9SHUT+FEED9+9CHILL+9ENG+9PRESS+9DRAIN
136 -	32.500	C	9XYGEN LOADING ALLSWANCE
137 -	33.000		9ALL9X=NOM9XL*(LA-1.)
138 -	34.000		MAX9XL=NOM9XL+9ALL9W
139 -	34.500	C	MAXIMUM 9XYGEN IN TANK
140 -	35.000		MAX9IT=MAX9XL-9BEL9W
141 -	35.500	C	9XYGEN VOLUME
142 -	36.000		9XV9L=MAX9IT/9DEN
143 -	35.500	C	ADD 9XYGEN ULLAGE VOLUME
144 -	37.000		T9VFL=9XV9L*JPER9
145 -	37.500	C	FUEL TANK HEIGHT AS FUNCTION OF TOTAL FUEL TANK V9L
146 -	37.600	C	REQUIRED LESS PREVIOUSLY CALC DEPENDENT VOLUMES
147 -	38.000		HH=(T9VIT*1728.-V9LA-V9LC)/(.7854*D**2)+HR
148 -	38.500		IF(HH.LT.HR) HH=HR
149 -	39.000		IF(3L<HD*GT.2.) V9LG=0.
150 -	39.500	C	9XY TANK CYL HEIGHT AS FUNCTION OF TOT 9XY TANK V8L
151 -	39.600	C	REQUIRED LESS PREV CALC DEP V8LS IF CBNE IS BIG
152 -	39.700	C	ENOUGH CYL HEIGHT (H9) IS SET EQUAL TO ZERO.
153 -	100.000		H9=(T9VFL*1728.-V9LD-V9LF-V9LG)/(.7854*D**2)
154 -	101.000		IF(H9.LT.0.) H9=0.
155 -	102.000		IF(3L<HD*GT.2.) HV=0.
156 -	103.500	C	CALCULATE OVERALL TANK LENGTH
157 -	103.000		L1=HN+HC+HH+HR+H9
158 -	104.000		IF(3L<HD*GT.1.0) L1=L1+HR+LCBN
159 -	104.500	C	ITERATE TO REQUIRED DIMENSIONAL CONSTRAINTS
160 -	105.000		IF(ABS(L1-L)*LT.1.) G9 TO 20
161 -	105.500		IF(LF*GT.0.) D=D*L1/LF
162 -	105.000		IF(D*GT.0.) L=L1
163 -	107.000		IF(D*GT.0.) G9 TO 15
164 -	109.000		IF(LD*GT.0.) L=(L1+L)/2.
165 -	110.000		G9 TO 10
166 -	111.000	20	L=L1
167 -	111.500	C	CALCULATE PR9P INVENTORY SUBTOTALS
168 -	112.000		UNDRAIN=9DRAIN+9DRAIN
169 -	113.000		FEEDTR=FEEDF*.3333+FEED9*.2418
170 -	114.000		PR9JRT=9PRESS+9RES+9PRES+9PRES
171 -	115.000		RESIDT=UNDRAIN+FEEDTR+PR9JRT+9BIAS
172 -	115.500	C	CALC RESULTING V9LS FOR CHECK AGAINST REQD V9LS
173 -	120.000		9XVLF=(V9LD+V9LF+V9LG+H9*.7854*D**2)/1728.
174 -	121.000		FUVLF=(V9LA+V9LC+(HH-HR)*.7854*D**2)/1728.
175 -	121.500	C	CALCULATE LIFT-OFF 9XYGEN HEAD HEIGHT, IS HEAD ABOVE
176 -	121.600	C	99 REL9W CBNE/CYL CONTOUR BREAK
177 -	122.000		H91=(9XV9L*1728.-V9LA)/(.7854*D**2)

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PROGRAM LISTING (Continued)

172 -	123.000		IF (491-3T-48) G9 T9 21
173 -	124.000		G9 T9 24
180 -	124.500	C	IF YES ITERATE FOR HEAD HEIGHT IN CONICAL SECTION
181 -	125.000	21	H9H1=H91-H9
182 -	124.000		9XV9L1=9XV9L*1728.-V9LA-H8*.7854*D**2
183 -	127.000	22	D1=D-2.*H9H1*TAN(THETA/57.2958)
184 -	128.000		V91=.2618*H9H1*(D**2+D*D1+D1**2)
185 -	129.000		IF (ABS(9XV9L1-V91).LT.100.) G9 T9 23
186 -	130.000		H9H1=(9XV9L1+H9H1)/V91
187 -	131.000		G9 T9 22
188 -	132.000	23	H9H=H9H1+H9
189 -	133.000		G9 T9 25
190 -	134.000	24	H9H=H91
191 -	134.500	C	CALCULATE LIFT-OFF FUEL HEAD HEIGHT
192 -	134.600	25	IF (44-EQ-HR) G9 T9 51
193 -	135.000		HFH=(V9LA-1728.*FJVB/L)/((1728.*DISPVF/(HH-HR)-.7854*D**2)
194 -	135.100		G9 T9 52
195 -	135.200	51	HFH=(V9LA-1728.*FJVB/L)/(-.7854*D**2)
196 -	135.500	C	9XY ULT ULLAGE PRESSURE
197 -	136.000	52	PULL9=FS*9PRES
198 -	136.500	C	FUEL ULT ULLAGE PRESSURE
199 -	137.000		PULLF=FS*9PRES
200 -	137.500	C	9XY AFT DOME ULT LIFT-OFF HEAD PRESSURE
201 -	138.000		9HDM1=(H9H+HR)*9DEN*VXL*FS/1728.
202 -	138.500	C	FUEL AFT DOME ULT LIFT-OFF HEAD PRESSURE
203 -	139.000		FHDM1=(HFH+HR)*FDEN*VXL*FS/1728.
204 -	139.500	C	2ND STAGE FUEL LOAD
205 -	140.000		FUEL2=PR992/(1.+4R)
206 -	140.500	C	2ND STAGE 9XYGEN LOAD
207 -	141.000		9XID2=FUEL2*4R
208 -	142.000		XFUL2=FUEL2+MAXFIT-FUEL-FSTART-FCHILL
209 -	143.000		9XID2=9XID2+MAX9IT-9XID-9START-9CHILL
210 -	143.500	C	2ND STAGE FUEL VOLUME
211 -	144.000		VXF2=XFUL2/FDEN
212 -	144.500	C	2ND STAGE 9XYGEN VOLUME
213 -	145.000		VX92=9XID2/9DEN
214 -	145.500	C	2ND STAGE FUEL HEAD HEIGHT
215 -	145.600		IF (44-EQ-HR) G9 T9 53
216 -	146.000		HFH2=(V9LA-1728.*VXF2)/((1728.*DISPVF/(HH-HR)-.7854*D**2)
217 -	146.100		G9 T9 54
218 -	146.200	53	HFH2=(V9LA-1728.*VXF2)/(-.7854*D**2)
219 -	147.000	54	IF (HFH2-LE-0.0) HFH2=0.0
220 -	147.500	C	CALCULATE 2ND STAGE 9XYGEN HEAD HEIGHT/IS HEAD
221 -	147.600	C	ARRIVE 9R HEL9W CONE/CYL CONTOUR BREAK
222 -	148.000		H92=(VX92*1728.-V9LA)/(.7854*D**2)
223 -	148.500		IF (492-3T-48) G9 T9 25
224 -	150.000		G9 T9 29
225 -	150.500	C	IF YES ITERATE FOR HEAD HEIGHT IN CONICAL SECTION
226 -	151.000	26	H9HX=H92-H9
227 -	152.000		9XV9L2=VX92*1728.-V9LA-H8*.7854*D**2
228 -	153.000	27	D2=D-2.*H9HX*TAN(THETA/57.2958)
229 -	154.000		V92=.2618*H9HX*(D**2+D*D2+D2**2)
230 -	155.000		IF (ABS(9XV9L2-V92).LT.100.) G9 T9 28
231 -	156.000		H9HX=(9XV9L2+H9HX)/V92
232 -	157.000		G9 T9 27
233 -	158.000	28	H9H2=H9HX+H8
234 -	158.100		G9 T9 50
235 -	158.200	29	H9H2=H92
236 -	158.300	C	9XY AFT DOME ULT 2ND STAGE HEAD PRESSURE
237 -	159.000	50	9HDM2=(H9H2+HR)*9DEN*VXS*FS/1728.
238 -	159.500	C	FUEL AFT DOME ULT 2ND STAGE HEAD PRESSURE

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233 -	160.000	FHDM2=(HFH2+HR)*FDEN*NXS*FS/1728.
240 -	160.500 C	ULT 9XY AFT DOME ULLAGE+HEAD PRES EITHER LIFT-
241 -	160.600 C	9FF 3R 2ND STAGE WHICHEVER IS GREATER.
242 -	161.000	P9DM4=PULL9+9HDM1
243 -	162.000	IF(9HDM2.GT.9HDM1) P9DM4=PULL9+9HDM2
244 -	162.500 C	ULT FUEL AFT DOME ULLAGE+HEAD PRES EITHER LIFT-
245 -	162.600 C	9FF 3R 2ND STAGE WHICHEVER IS GREATER.
246 -	163.000	PFD9M=PULLE+FHDM1
247 -	164.000	IF(FHDM2.GT.FHDM1) PFD9M=PULLE+FHDM2
248 -	164.500 C	INITIALLY SET WT'S & T'S TO ZERO BEFORE BEGINNING
249 -	164.600 C	MULTI-STATION ANALYSIS.
250 -	165.000	WFX=0.
251 -	166.000	WFX=0.
252 -	167.000	WLOFX=0.
253 -	168.000	WLOFX=0.
254 -	169.000	TAF=0.
255 -	170.000	TAF=0.
256 -	170.500 C	MULTI-STATION ANALYSIS (FUEL TANK REFERS TO AFT TANK
257 -	170.600 C	AND 9XY TANK REFERS TO FWD TANK) THE REVERSE IS LITERALLY
258 -	170.700 C	TRUE FOR THE L9X AFT OPTION BECAUSE OF LINE 18.5
259 -	170.800 C	AT BEGINNING OF PROGRAM) THE FWD AND AFT TANKS ARE
260 -	170.900 C	THEREFORE ANALYZED IDENTICALLY IN THE EVENT THAT THE FWD
261 -	170.910 C	TK IS LARGE AND THE AFT TK IS SMALL AND VICE VERSA)
262 -	171.000	OR 84 I=1,9
263 -	172.000	HF=HF+HR
264 -	172.500 C	SET STATION LOCATIONS FOR FUEL TANK CYL WALL ANALYSIS
265 -	173.000	HFX(I)=.125*(I-1)*HF
266 -	173.500 C	CALCULATE FUEL TK CYL WALL HEAD PRES @ HFX(I)
267 -	173.600 C	ABOVE CYL BASE BY COMPARING WITH LIFT-9FF AND
268 -	173.700 C	2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
269 -	174.000	FHC2=(HFH2-HFX(I))*FDEN*NXS*FS/1728.
270 -	175.000	FHC1=(HFH-HFX(I))*FDEN*NXL*FS/1728.
271 -	175.000	IF(FHC1.LT.FHC2) 39 TO 59
272 -	177.000	FHCX=FHC1
273 -	178.000	59 TO 60
274 -	179.000	59 FHCX=FHC2
275 -	180.000	60 IF(FHCX.LE.0.) FHCX=0.
276 -	180.500 C	ADD FUEL ULLAGE PRESS TO RESULTING HEAD PRESSURE
277 -	181.000	FHCT(I)=FHCX+PULLE
278 -	181.500 C	SET STATION LOCATIONS FOR 9XY TANK CYL WALL ANALYSIS
279 -	182.000	H9X(I)=.125*(I-1)*H9
280 -	182.000 C	CALCULATE 9XY TK CYL WALL HEAD PRES @ H9X(I)
281 -	183.000 C	ABOVE CYL BASE BY COMPARING WITH LIFT-9FF AND
282 -	183.200 C	2ND STAGE HEAD HEIGHTS AS CALCULATED PREVIOUSLY
283 -	184.000	9HCP2=(H9H2-H9X(I))*9DEN*NXS*FS/1728.
284 -	187.000	9HC1=(H9H-H9X(I))*9DEN*NXL*FS/1728.
285 -	188.000	IF(9HC1.LT.9HCP2) 39 TO 63
286 -	189.000	9HCX=9HC1
287 -	190.000	59 TO 64
288 -	191.000	63 9HCX=9HCP2
289 -	192.000	64 IF(9HCX.LE.0.) 9HCX=0.
290 -	192.500 C	ADD 9XY ULLAGE PRESS TO RESULTING HEAD PRESSURE
291 -	193.000	9HCT(I)=9HCX+PULL9
292 -	193.500 C	CALCULATE FUEL TANK BENDING MOMENTS
293 -	194.000	M(I)=0.
294 -	194.500 C	CALCULATE 9XY TANK BENDING MOMENTS
295 -	195.000	M9(I)=0.
296 -	195.500 C	CALCULATE FUEL TK THICKNESS REQUIRED DUE TO ULT PRES
297 -	196.000	TF(I)=FHCT(I)*D*.5/FTJ
298 -	196.500 C	CALCULATE 9XY TK THICKNESS REQUIRED DUE TO ULT PRES
299 -	197.000	TR(I)=9HCT(I)*D*.5/FTJ

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PROGRAM LISTING (Continued)

300 -	137.500 C	CHECK FUEL TK THICKNESS & SET = OR GREATER THAN TMIN
301 -	138.000	IF(TF(I)-LT-TMIN) TF(I)=TMIN
302 -	138.500 C	CHECK BXY TK THICKNESS & SET = OR GREATER THAN TMIN
303 -	139.000	IF(T9(I)-LT-TMIN) T9(I)=TMIN
304 -	139.500 C	CALCULATE JLT LIFT-OFF & 2ND STAGE AXIAL LOAD USE
305 -	139.600 C	WHICHEVER IS GREATER.
306 -	200.000	AL1=MAXBIT*FS*NXL
307 -	201.000	AL2=XPXD2*FS*NXS
308 -	202.000	AL=AL1
309 -	203.000	IF(AL2>AL1) AL=AL2
310 -	203.500 C	CHECK MARGIN OF SAFETY FOR COLUMN BUCKLING FOR B.M.'S
311 -	203.600 C	AND AXIAL LOAD WITH INTERNAL PRESSURE STABILIZATION
312 -	204.000	FRST=.5*D/TF(I)
313 -	205.000	FLR2=(L-HC-HR-HV-HFX(I))/(.5*D)
314 -	206.000	RXT=FRST
315 -	207.000	LXR=FLR2
316 -	208.000	TX=TF(I)
317 -	209.000	PRES=FUPRES
318 -	210.000	MX=MF(I)
319 -	211.000	G9 T9 70
320 -	212.000	69 RXT=FRST
321 -	213.000	LXR=FLR2
322 -	214.000	TX=T9(I)
323 -	215.000	PRES=9UPRES
324 -	216.000	MX=M9(I)
325 -	217.000	AL=0.
326 -	217.500 C	CURVE FIT OF BRJHN'S GRAPHS
327 -	218.000	70 IF(LXR>GT.1.0) G9 T9 73
328 -	219.000	A=7.34127+.269862*LXR
329 -	220.000	IF(LXR>GT..26) G9 T9 71
330 -	221.000	F=7.26403+7.93752*LXR
331 -	222.000	G9 T9 79
332 -	223.000	71 IF(LXR>GT..5) G9 T9 72
333 -	224.000	F=9.34345
334 -	225.000	G9 T9 79
335 -	226.000	72 F=9.62181+.59176*LXR
336 -	227.000	G9 T9 79
337 -	228.000	73 IF(LXR>GT.4.0) G9 T9 74
338 -	229.000	A=8.30526+.671566*LXR
339 -	230.000	IF(LXR>LT.2.0) G9 T9 72
340 -	231.000	75 F=8.88855+.212134*LXR
341 -	232.000	G9 T9 79
342 -	233.000	74 IF(LXR>GT.6.0) G9 T9 76
343 -	234.000	A=5.61685
344 -	235.000	G9 T9 75
345 -	236.000	76 IF(LXR>GT.16.0) G9 T9 77
346 -	236.500	A=6.47239+.144808*LXR
347 -	237.000	IF(LXR>LT.8.0) G9 T9 75
348 -	238.000	78 F=8.25156+.133275*LXR
349 -	239.000	G9 T9 79
350 -	240.000	77 A=5.14063+.061365*LXR
351 -	241.000	G9 T9 78
352 -	242.000	79 B=LXR/(-.624947*LXR+.007487)
353 -	243.000	G=LXR/(-.426078*LXR+.008016)
354 -	243.500 C	CRITICAL STRESS CALCULATION
355 -	244.000	80 FCR=A*RXT**3
356 -	245.000	FCR=FCR+E
357 -	246.000	FPR=F*RXT**3
358 -	247.000	FPR=FPR+E
359 -	247.500 C	CORRECT FOR INTERNAL PRESSURE STABILIZATION
360 -	248.000	PYE=PRES*RXT**2/E

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361 -	249.000	DELAX=PX/(4.41405*PX+.603553)
362 -	250.000	DLFCR=DELAX*.E*TX/.5*D
363 -	251.000	FPT=PRES*.5*D/(2.*TX)
364 -	252.000	PA=(FCR+DLFCR+FPT)*2.38451*D*TX
365 -	253.000	DELRH=.376601*PX+.210492
366 -	254.000	DLFRH=DELRH*.E*TX/(.5*D)
367 -	255.000	MA=(FBR+DLFRH+FPT)*.74612*TX*D**2
368 -	255.500 C	CALCULATE MARGIN OF SAFETY AND INCREASE T IF INADEQUATE
369 -	256.000	RCB=AL/PA+MX/MA
370 -	257.000	IF(RCB.LT.1.0) G9 T8 R1
371 -	258.000	TX=TX+.001
372 -	259.000	RYT=.5*D/TX
373 -	260.000	G9 T9 R0
374 -	261.000	R1 IF(FLDR.EQ.LXR) G9 T9 R2
375 -	262.000	IF(FLDR.EQ.LXR) G9 T9 R3
376 -	263.000	R2 TF(I)=TX
377 -	263.500 C	SUM FUEL TANK T'S FOR AVERAGE CALCULATION
378 -	264.000	TAF=TAF+TF(I)
379 -	265.000	PRRT=.5*D/T9(I)
380 -	266.000	PLR2=(49-HRX(I))/(.5*D)
381 -	267.000	G9 T9 R9
382 -	268.000	R3 T9(I)=TX
383 -	268.500 C	SUM GXY TANK T'S FOR AVERAGE CALCULATION
384 -	269.00	TAG=TAG+T9(I)
385 -	269.500 C	CALC FUEL TK CYL WALL WT ADD .005 TO T FOR MATL TOLERANCE
386 -	270.000	WF(I)=(TF(I)+.005)*3.14159*D*.125*HR*RH
387 -	271.000	WFX=WFX+WF(I)
388 -	271.500 C	CALC FUEL TK CIRCUMFERENTIAL WELDS @ 3.5 WIDE
389 -	272.000	WLOF(I)=(TF(I)+.005)*3.14159*D*3.5*RH
390 -	273.000	WLOFX=WLOFX+WLOF(I)
391 -	273.500 C	CALC GXY TK CYL WALL WT ADD .005 TO T FOR MATL TOLERANCE
392 -	274.000	W9(I)=(T9(I)+.005)*3.14159*D*.125*HR*RH
393 -	275.000	W9X=W9X+W9(I)
394 -	275.500 C	CALC GXY TK CIRCUMFERENTIAL WELDS @ 3.5 WIDE
395 -	276.000	WLO9(I)=(T9(I)+.005)*3.14159*D*3.5*RH
396 -	277.000	WLO9X=WLO9X+WLO9(I)
397 -	278.000	R4 CONTINUE
398 -	278.500 C	DELETE MID CIRC WELDS IF TK IS SHORT I.E. L9X AFT/FWD
399 -	279.000	IF(49.GT.44) G9 T9 R5
400 -	280.000	WLO9T=WLO9(I)+WLO9(9)
401 -	281.000	WLOFT=WLOFX
402 -	282.000	G9 T9 R6
403 -	283.000	R5 WLO9T=WLO9X
404 -	284.000	WLOFT=WLOF(I)+WLOF(9)
405 -	284.500 C	RING MINIMUM GAUGE
406 -	285.000	R6 AMIN=14.*TMIN
407 -	285.500 C	AVERAGE FUEL TANK T
408 -	286.000	AVFT=TAF/9.
409 -	286.500 C	AVERAGE GXYGEN TANK T
410 -	287.000	AVGT=TAG/9.
411 -	287.500 C	CALC N9. OF LONGITUDINAL WELDS BASED ON 156 WIDE SHEET
412 -	288.000	CIR=3.14159*D
413 -	289.000	D9 R7 I=1,100
414 -	290.000	SX=156.*I
415 -	291.000	IF(SX.GT.CIR) G9 T9 R8
416 -	292.000	R7 CONTINUE
417 -	293.000	R8 SEG=SX/156.
418 -	293.500 C	CALCULATE INTER-TANK SECTION WEIGHT
419 -	294.000	TINT=T9(I)
420 -	295.000	IF(T9(I).LT.TF(9)) TINT=TF(9)
421 -	296.000	WINT=(3.14159*D*3.5*SEG)*(TINT+.005)*(2.*HR+LC9N)*RH

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422 -	297.000	IF(BLKHD.EQ.1.0) WINT=0.
423 -	298.000 C	CALCULATE FUEL TK LONGITUDINAL WELD WEIGHT
424 -	300.000	LWLD9=HF*SEG*3.5*(AVFT+.005)*RH9
425 -	301.000	IF(BLKHD.EQ.1.0) LWLD9=HH*SEG*3.5*(AVFT+.005)*RH9
426 -	301.500 C	CALCULATE 9XY TK LONGITUDINAL WELD WEIGHT
427 -	302.000	LWLD9=49*SEG*3.5*(AVFT+.005)*RH9
428 -	302.500 C	AFT FUEL BLKHD THICKNESS
429 -	303.000	TAFB=PF094*R/(2.*FTU)
430 -	304.000	IF(TAFB.LT.TMIN) TAFB=TMIN
431 -	304.500 C	AFT FUEL BLKHD RING AREA SIZED FOR ELASTIC STABILITY
432 -	305.000	NAFR=(PF094*R/2.)*SIN(30./57.2958)
433 -	306.000	AAFR=(NAFR*(.5*3))*3/(3.*E))*5
434 -	307.000	IF(AAFR.LT.AMIN) AAFR=AMIN
435 -	307.500 C	AFT 9XY BLKHD THICKNESS
436 -	308.000	TAFB=PF094*R/(2.*FTU)
437 -	309.000	IF(TAFB.LT.TMIN) TAFB=TMIN
438 -	309.500 C	AFT 9XY BLKHD RING AREA SIZED FOR ELASTIC STABILITY
439 -	310.000	NAFR=(PF094*R/2.)*SIN(30./57.2958)
440 -	311.000	AAFR=(NAFR*(.5*3))*3/(3.*E))*5
441 -	312.000	IF(AAFR.LT.AMIN) AAFR=AMIN
442 -	312.500 C	FWD FUEL BLKHD THICKNESS
443 -	313.000	TFEB=PULLF*R/(2.*FTU)
444 -	314.000	IF(TFEB.LT.TMIN) TFEB=TMIN
445 -	314.500 C	FWD FUEL BLKHD RING AREA SIZED FOR ELASTIC STABILITY
446 -	315.000	NFEF=(PULLF*R/2.)*SIN(30./57.2958)
447 -	316.000	AFFR=(NFEF*(.5*3))*3/(3.*E))*5
448 -	317.000	IF(AFFR.LT.AMIN) AFFR=AMIN
449 -	317.500 C	WEIGHT OF AFT 9XY BLKHD RING AND WELD
450 -	318.000	WA33=(TAFB+.005)*2.*3.14159*R*HR*RH9
451 -	319.000	WA92=3.14159*D*RH9*AAFR
452 -	320.000	WA94=RH9*3.5*(TAFB+.005)*3.14159*(.333*R*SEG+D)
453 -	320.500 C	WEIGHT OF FWD FUEL BLKHD RING AND WELD
454 -	321.000	WAFB=(TAFB+.005)*2.*3.14159*R*HR*RH9
455 -	322.000	WAFW=3.14159*D*RH9*AAFR
456 -	323.000	WAFW=RH9*3.5*(TAFB+.005)*3.14159*(.333*R*SEG+D)
457 -	323.500 C	WEIGHT OF FWD FUEL BLKHD RING AND WELD
458 -	324.000	WFEF=(TFEB+.005)*2.*3.14159*R*HR*RH9
459 -	325.000	WFEF=3.14159*D*RH9*AAFR
460 -	326.000	WFEF=RH9*3.5*(TFEB+.005)*3.14159*(.333*R*SEG+D)
461 -	327.000	IF(BLKHD.EQ.1.0) G9 T9 90
462 -	328.000	G9 T9 91
463 -	328.500 C	COMMON BLKHD T-BAR BASED ON REVERSE FUEL ULLAGE
464 -	329.000 C	PRESSURE AND IS3-GRID MATL.
465 -	329.500 90	TCFB=(.000614*(.0000205*FBPRES))*R
466 -	329.500 C	WEIGHT OF COMMON FUEL BLKHD AND WELD
467 -	330.000	WCFB=TCFB*2.*3.14159*R*HR*RH9
468 -	331.000	WCFW=RH9*3.5*TCFB*3.14159*(.333*R*SEG+D)
469 -	331.500 C	CHECK WITH AFT 9XY BLKHD TENSION LOAD REQMTS
470 -	332.000	IF(WCFB.LT.WABB) WCFB=WABB
471 -	333.000	IF(WCFW.LT.WABW) WCFW=WABW
472 -	334.000	WFEF=WCFB
473 -	335.000	WFEF=WCFW
474 -	336.000	WA94=0.
475 -	337.000	WA99=0.
476 -	338.000	WFEF=WA99
477 -	339.000	WA92=0.
478 -	339.500 C	FWD CONE AND FAIRING ANALYSIS
479 -	340.000 91	IF(BLKHD.GT.2.0) G9 T9 92
480 -	340.500 C	UPR CONE WALL THICKNESS
481 -	341.000	TUCN=PULLD*BR/FTU
482 -	342.000	IF(TUCN.LT.TMIN) TUCN=TMIN

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483 -	342.500	C	FWD 9XY BLKHD THICKNESS
484 -	343.000		TF93=PULL9*9R/(2.*FTU)
485 -	344.000		IF(TF93.LT.TMIN) TF93=TMIN
486 -	344.500	C	FWD 9XY BLKHD RING AREA SIZED FOR ELASTIC STABILITY
487 -	345.000		VF92=ABS((PULL9/2.)*(9R*SIN(30./57.2958))-5*9D*TAN(THETA/
488 -	345.000		57.2958)))
489 -	347.000		AF92=(VF92*(.5*9D)**3/(3.*E))**.5
490 -	348.000		IF(AF92.LT.AMIN) AF92=AMIN
491 -	348.500	C	WEIGHT OF FWD 9XY BLKHD RING AND WELD
492 -	349.000		WF92=3.14159*9D*RH9*AF92
493 -	350.000		WF93=(TF93+.005)*2.*3.14159*9R*RH9*RH9
494 -	351.000		WF94=RH9*3.5*(TF93+.005)*3.14159*(.333*9R*SEG*9D)
495 -	351.500	C	WEIGHT OF FWD FAIRING USING MINIMUM GAUGE PLUS WELDS
496 -	352.000		WFAIR=RH9*(TMIN+.005)*3.14159*(2.*NR*HV*(.5*9D+.5*ND)*
497 -	353.000		5*((HC-HC9)**2*(.5*9D+.5*ND)**2)**.5)
498 -	354.000		WFAW=RH9*3.5*(TMIN+.005)*(3.14159*ND+SEG*(HC-HC9)/
499 -	355.000		57.2958))
500 -	355.500	C	WEIGHT OF FWD CONE 9XY TANK WALL AND WELDS
501 -	356.000		WC9N=RH9*3.14159*.5*((TUCN+.005)*9D+(T9(9)+.005)*D)*HC9/
502 -	357.000		57.2958)
503 -	358.000		WC9NW=RH9*3.5*((TUCN+T9(9))*5+.005)*SEG*HC9/C9S(THETA/
504 -	359.000		57.2958)+3.14159*(TUCN+.005)*9D)
505 -	360.000		9D T9 33
506 -	360.500	C	ALTERNATE FWD SECTION WITHOUT FAIRING
507 -	360.600	C	FWD 9XY BLKHD THICKNESS
508 -	361.000	92	TF93=PULL9*.5*ND/(2.*FTU)
509 -	362.000		IF(TF93.LT.TMIN) TF93=TMIN
510 -	362.500	C	UPR CONE WALL THICKNESS
511 -	363.000		TUCN=PULL9*.5*ND/FTU
512 -	364.000		IF(TUCN.LT.TMIN) TUCN=TMIN
513 -	365.000	C	FWD 9XY BLKHD RING AREA SIZED FOR ELASTIC STABILITY
514 -	370.000		VF92=ABS((PULL9/2.)*(5*ND*SIN(30./57.2958))-5*ND*TAN(
515 -	371.000		57.2958)))
516 -	372.000		AF92=(VF92*(.5*ND)**3/(3.*E))**.5
517 -	373.000		IF(AF92.LT.AMIN) AF92=AMIN
518 -	373.500	C	WEIGHT OF FWD 9XY BLKHD RING AND WELD
519 -	374.000		WF92=3.14159*ND*RH9*AF92
520 -	375.000		WF93=RH9*(TF93+.005)*2.*3.14159*(.5*ND)**2
521 -	376.000		WF94=RH9*3.5*(TF93+.005)*3.14159*ND
522 -	377.000		WFAIR=0.
523 -	378.000		WFAW=0.
524 -	378.500	C	WEIGHT OF FWD CONE 9XY TANK WALL AND WELDS
525 -	379.000		WC9N=RH9*3.14159*.5*((TUCN+.005)*ND+(T9(9)+.005)*D)*HC9/
526 -	380.000		57.2958)
527 -	381.000		WC9NW=RH9*3.5*((TUCN+T9(9))*5+.005)*SEG*HC9/C9S(THETA/
528 -	382.000		57.2958)+3.14159*(TUCN+.005)*ND)
529 -	382.500	C	FWD CONE/CYL RING AREA SIZED FOR ELASTIC STABILITY
530 -	383.000	93	NCCR=9DCT(9)*(.5*9D)*TAN(THETA/57.2958)/2.
531 -	384.000		ACCR=(NCCR*(.5*9D)**3/(3.*E))**.5
532 -	385.000		IF(ACCR.LT.AMIN) ACCR=AMIN
533 -	385.500	C	WEIGHT OF FWD CONE/CYL RING AND WELDS
534 -	386.000		NCCR=3.14159*9D*RH9*ACCR
535 -	387.000		ACCR=3.14159*9D*RH9*(T9(9)+.005)*3.5
536 -	387.500	C	WEIGHT OF MISC STR COMPONENTS/UMBILICAL PANELS/
537 -	387.600	C	TUNNEL/ AND RAFFLES
538 -	388.000		UMRPNL=300.
539 -	389.000		TUNNEL=200.*L/1694.
540 -	389.500		IF(3L<4D*.GT.1.0) TUNNEL=446.*L/1475.
541 -	390.000		RAFF=0*(HR+HC9)/343.
542 -	391.000		IF(3L<4D*.GT.2.0) RAFF=0*(HR+HC)/343.
543 -	392.000		IF(49.GT.44) RAFF=0*HF/343.

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PROGRAM LISTING (Continued)

544 -	332.500	C	STRUCTURAL WEIGHT SUBTOTALS
545 -	333.000		FWDRLF=WFRF+WFRB+WFRW
546 -	334.000		CNSCT=WCRN+WCRNW+WCCR+WCCW
547 -	335.000		CYLSCT=WFX+WLDRT+LWLD9
548 -	336.000		AFTRLF=WARR+WARR+WABW
549 -	337.000		FWDTK=FWDRLF+CNSCT+CYLSCT+AFTRLF
550 -	338.000		FWDRL=WFRB+WFRF+WFRW
551 -	339.000		AFTCYL=WFX+WLDRT+LWLD9
552 -	400.000		AFTRLA=WARR+WARR+WABW
553 -	401.000		AFTNK=FWDRLA+AFTCYL+AFTRLA
554 -	402.000		NDSFAR=WFAIR+WFAW
555 -	403.000	C	SET D=9.0. JRE-DEFINE L/D
556 -	410.000		D=D+2.*K
557 -	411.000		L/D=L/D
558 -	412.000	C	CALCULATE INDUCED ENVIRN PROT WITH 10% NON-80T
559 -	413.500	C	INTER TANK TPS
560 -	420.000		TPSIN=((2.*HR+LC9N)*3.14159*D)*INTPS/144.)*1.10
561 -	420.500	C	NDS FAIRING TPS
562 -	421.000		TPSFA=3.14159*.5*(UCTPS*ND+LCTPS*D)*(HC-HC0)/
563 -	422.000		S(C95(THETA/57.2958)*144.))
564 -	422.500	C	NDS CAP TPS
565 -	423.000		TPSNC=NCTPS*3.14159*2.*NR*HN/144.
566 -	424.000		IF(49.GT.44) G9 T9 97
567 -	424.400	C	LAX FWD TPS
568 -	424.500	C	AFT CSNE TPS
569 -	425.000		TPSCN=DMTPS*2.*3.14159*R*HR/144.
570 -	425.500	C	AFT CYLINDER TPS
571 -	426.000		TPSCY=3.14159*D*HF*CYTPS/144.
572 -	427.000		TPSCN=0.
573 -	428.000		TPSCY=0.
574 -	429.000		IF(44.HQ.EQ.1.) G9 T9 94
575 -	430.000		G9 T9 95
576 -	430.500	C	AFT CYLINDER TPS FOR COMMON BLKHD CASE
577 -	431.000	94	TPSCY=3.14159*D*HF*CYTPS/144.
578 -	432.000		TPSIN=0.
579 -	433.000	95	IF(44.HQ.GT.2.) G9 T9 96
580 -	434.000		G9 T9 101
581 -	435.000	96	TPSFA=0.
582 -	436.000		TPSNC=0.
583 -	437.000		G9 T9 101
584 -	437.400	C	LAX AFT TPS
585 -	437.500	C	FWD CSNE TPS
586 -	438.000	97	TPSCN=3.14159*.5*(LCTPS*D+CYTPS*D)*HC0/
587 -	439.000		S(C95(THETA/57.2958)*144.))
588 -	439.500	C	FWD CYLINDER TPS
589 -	440.000		TPSCY=3.14159*CYTPS*D*48/144.
590 -	441.000		TPSCN=0.
591 -	442.000		TPSCY=0.
592 -	443.000		IF(44.HQ.EQ.1.) G9 T9 98
593 -	444.000		G9 T9 99
594 -	445.000	98	TPSIN=0.
595 -	445.000	99	IF(44.HQ.GT.2.) G9 T9 100
596 -	447.000		G9 T9 101
597 -	447.500	C	ALTERNATE FWD SECTION WITHOUT FAIRING
598 -	448.000	100	TPSFA=0.
599 -	449.000		TPSNC=0.
600 -	449.500	C	FWD CSNE TPS
601 -	450.000		TPSCN=3.14159*.5*(UCTPS*ND+LCTPS*D)*HC0/
602 -	451.000		S(C95(THETA/57.2958)*144.))
603 -	451.500	C	TPS WEIGHT SUBTOTALS WITH 10% NON-9PTIMUM
604 -	452.000	101	FAIRT=(TPSFA+TPSNC)*1.10



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605 -	453.000	FCCTPS=(TPSCN+TPSCU)*1.10
606 -	454.000	ACYDM=(TPSCM+TPSCY)*1.10
607 -	455.000	TPPS=TPSIN+FAIRI+FCCTPS+ACYDM
608 -	455.500 C	INTERSTAGE ANALYSIS
609 -	455.600 C	LR=SPACE BETWEEN 390STER ATTACH POINTS
610 -	456.000	LR=44+LC9N+HR+49
611 -	457.000	IF (BLK4D.EQ.1.) LB=44+49
612 -	457.500 C	390STER INDUCED MOMENT AND REACTIONS
613 -	458.000	M6=(THBSL/NN)*COS(CANT/57.2958)*78.
614 -	460.000	S=(THBSL/NN)*SIN(CANT/57.2958)*27.
615 -	461.000	R6=(M6/LB)*FS
616 -	462.000	R5=((THBSL/NN)*SIN(CANT/57.2958)-R6)*FS
617 -	463.000	R6=((THBSL/NN)*COS(CANT/57.2958)-B3LOW/NN)*FS
618 -	463.500 C	GENERALIZED WT EQ FOR RING CAPS, WEBS AND BEAM
619 -	463.600 C	CAPS, WEBS, 94*FTU KNICK DOWN FACTOR FOR COMP STAB
620 -	463.700 C	.3125*FTU FOR SHEAR ALLOWABLE)
621 -	464.000	WIT=(RH9*1.10/(2.*FTU))*(3.14159*(D/.94+40./3125)
622 -	465.000	S+D*.2/(40.*.94)+D/.3125)
623 -	465.500 C	WEIGHT OF 390STER ATTACH RINGS-CHECK AGAINST BLK4D
624 -	465.600 C	RINGS AND ADD INTERSTAGE REEF-UP REQMTS
625 -	466.000	M6=WIT*NN*R6
626 -	467.000	M5=WIT*NN*R5
627 -	467.100	IF (M6.GT.*CCR) M6=M6-CCCR
628 -	467.200	IF (M6.GT.*CCR) G9 TO 130
629 -	467.300	M6=0.
630 -	467.400	130 IF (M5.GT.*AFR) M5=M5-AFR
631 -	467.500	IF (M5.GT.*AFR) G9 TO 131
632 -	467.600	M5=0.
633 -	467.700 C	ADD SEPARATE ORBITER ATTACH RINGS BASED ON ORBITER
634 -	467.800 C	REACTION LOADS FROM ORBITER MODULE
635 -	468.000	131 W2=WIT*R2*.716
636 -	469.000	W1=WIT*R1*.2055
637 -	469.500 C	ADD SPECIAL INCREMENTS FOR SWAY BRACES DOUBLERS
638 -	469.600 C	DRAW LINKS AND FITTINGS-ADD 10X STR NON-SPT
639 -	470.000	WSL=45.
640 -	471.000	ASR=(R1*12.*(1.5D*.5774)*.2/(E*3.14159*.2))*.5
641 -	472.000	WSR=ASR*.5D*.5774*R4*.2*.134*1.05
642 -	473.000	WSF=8.284*(R6*3./((.3125*FTU))*.15*2.*RH9*1.10
643 -	474.000	WFDJB=150.*.5*3.14159*.2*RH9*.071*1.10
644 -	475.000	WDRAW=.5*100.*RH9*1.10*(NN*R3+RL)/(.94*FTU)
645 -	476.000	WADJB=100.*.5*3.14159*.2*RH9*.055*1.10
646 -	477.000	W9LL=R2*39.*.2.*RH9*1.34*1.10/FTU
647 -	478.000	WSLS=35.
648 -	479.000	WSLF=55.
649 -	480.000	W9LL=R5*1.5*78.*.4.*RH9*1.34*1.10/FTU
650 -	480.500 C	TOTAL INTERSTAGE WEIGHT
651 -	481.000	TWINT=M6+M5+W2+W1+WSL+WSB+WSF+WFDJB+WDRAG+WADJB
652 -	482.000	S+W9LL+WSLS+WSLF+W9LL
653 -	482.500 C	TOTAL STRUCTURE WEIGHT
654 -	483.000	390GRP=FWDTK+WINT+AFTTK+V8SFAR+TWINT+UMBPNL+TUNNEL+BAFF
655 -	483.500 C	PROPELLANT SYSTEMS-BASED ON DETAIL POINT DESIGN WITH
656 -	483.600 C	SCALING LAWS FOR ORBITER ENGINE FLOW RATE, MIXTURE
657 -	483.700 C	RATIO AND TANK DIMENSIONS
658 -	484.000	IF (BLK4D.GT.1.0) G9 TO 103
659 -	484.500 C	COMPUTE BLK4D INTERNAL LUX LINE
660 -	485.000	9XVENT=564.
661 -	486.000	4VENT=427.
662 -	487.000	PNEJ=.25*.5*30*.5*L/1594.
663 -	488.000	IF (49.GT.44) G9 TO 102
664 -	488.500 C	LAX FORWARD
665 -	489.000	9XPRES=122.*.109.*L/1694.

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PROGRAM LISTING (Continued)

666 -	490.000	9XFEED=(18.5+.01222*HF)*9FL9WY**5
667 -	491.000	HPRES=61+.83*.4F/898.
668 -	492.000	HFEEED=(31.59+.03176*2)*9FL9WY**5
669 -	493.000	RX=.5*(7+.33*9FL9WY**5)
670 -	494.000	GR T9 105
671 -	494.500 C	L9X AFT
672 -	495.000	102 9XPRES=122+.109*.4F/1694.
673 -	496.000	9XFEED=(18.5+.01222*.5*2)*9FL9WY**5
674 -	497.000	HPRES=61+.83*.4L/898.
675 -	498.000	HFEEED=(31.59+.03176*.4F)*9FL9WY**5
676 -	499.000	RX=.5*(7+.76*9FL9WY**5)
677 -	500.000	GR T9 105
678 -	500.500 C	SEPARATE BLKHDS EXTERNAL L9X LINES
679 -	501.000	103 PNEJ=P5.5+18.5*L/1470.
680 -	502.000	WUJKT=0.
681 -	503.000	RX=0.
682 -	504.000	9XVENT=522.
683 -	505.000	HCIP=68+.100*.2/314.
684 -	506.000	HVENT=522.
685 -	507.000	IF(49.GT.44) GR T9 104
686 -	507.500 C	L9X FORWARD
687 -	508.000	9XPRES=128+.132*.4L/1470.
688 -	509.000	9XFEED=(18.1+.01465*(44+LC9N))*9FL9WY**5
689 -	510.000	HPRES=69+.115*.4H/703.
690 -	511.000	HFEEED=(34.21+.01333*2)*9FL9WY**5
691 -	512.000	GR T9 106
692 -	512.500 C	L9X AFT
693 -	513.000	104 9XPRES=128+.132*.4H/1470.
694 -	514.000	9XFEED=(18.1+.01465*.5*2)*9FL9WY**5
695 -	515.000	HPRES=69+.115*.4L/703.
696 -	516.000	HFEEED=(34.21+.01333*(44+LC9N))*9FL9WY**5
697 -	517.000	GR T9 106
698 -	517.500 C	COMMON BLKHD. INTERNAL L9X LINE JACKET UNDER EXTERNAL PRES
699 -	518.000	105 TTAP=(FHCT(9)*10*(RX+3))*1.5/(E*.88157))**.4
700 -	519.000	IF(TTAP*LT*TMIN) TTAP=TMIN
701 -	520.000	TBAT=(FHCT(1)*10*(RX+3))*1.5/(E*.88157))**.4
702 -	521.000	IF(TBAT*LT*TMIN) TBAT=TMIN
703 -	522.000	WJACK=(.5*(TTAP+TBAT)+.005)*3.14159*2*(RX+3)*.25
704 -	523.000	5*.447*(HF-100.)
705 -	524.000	TUPR=(FHCT(9)*10*(RX+3))*1.5/(E*.88157))**.4
706 -	525.000	IF(TUPR*LT*TMIN) TUPR=TMIN
707 -	526.000	TLWR=(FHCT(1)*10*(RX+3))*1.5/(E*.88157))**.4
708 -	527.000	IF(TLWR*LT*TMIN) TLWR=TMIN
709 -	528.000	WEND=(TUPR+TLWR+.01)*50*.3*1.4159*(RX+3)*.2.
710 -	529.000	5*.1.25*RH9
711 -	530.000	WUJKT=1.10*(WJACK+WEND)
712 -	531.000	HCIP=0.
713 -	531.500 C	MISC PRAP SYS C9M9NENTS/SJMP,PUSYS
714 -	532.000	106 SUMP=220.
715 -	533.000	PUSYS=185.
716 -	533.500 C	PROPELLANT SYSTEMS SUBTOTALS
717 -	534.000	FEDSYS=9XFEED+HFEEED+WUJKT+HCIP
718 -	535.000	PRSVNT=HPRES+HVENT+9XPRES+9XVENT
719 -	536.000	PNEJ=PNEU+PUSYS
720 -	537.000	PRSSYS=FEDSYS+PRSVNT+PNEJ+SUMP
721 -	537.500 C	ESTIMATED TANK INERT WT FOR RETRO SYS CALCULATION
722 -	538.000	XDRY=(B9DGRP+T9TPS+PRSSYS+AVIGN+MISC)*(1.+GUP)
723 -	539.000	XINERT=XDRY+RESIDT
724 -	539.500 C	RETRO ROCKET SIZING
725 -	540.000	DELX=EXP(RETQV/(32.17*RETISP))-1.
726 -	541.000	WRPR9P=XINERT*DELX/(1.-(1.+GUP)*.365*DELX)

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727 - 542.000      WRETR8=1.745*WRPR9P
728 - 542.500 C    TANK SUBTOTAL DRY WEIGHT
729 - 543.000      SUBDRY=890GRP+T9TPS+PR9SYS+AVIGN+MISC+WRETR8
730 - 543.500 C    GROWTH/UNCERTAINTY AS PERCENT OR DELTA TO A FIXED
731 - 543.600 C    DRY WEIGHT
732 - 544.000      GU=SUBDRY*GUP
733 - 545.000      IF(FIXDWT.GT.0.) GU=FIXDWT-SUBDRY
734 - 545.500 C    TANK TOTAL DRY WEIGHT
735 - 546.000      DRYWT=SUBDRY+GU
736 - 546.500 C    TANK TOTAL INERT WEIGHT
737 - 547.000      INERT=DRYWT+RESIDT
738 - 547.500 C    EXTERNAL TANK GROSS WEIGHT
739 - 548.000      GROSSA=INERT+PR9PB
740 - 548.500 C    EXTERNAL TANK MASS FRACTION
741 - 549.000      LAMBDA=PR9PB/GROSSW
742 - 550.000 C
743 - 551.000 C
744 - 552.000 C    THIS CONCLUDES THE SIZING LOGIC THE FOLLOWING ARE
745 - 553.000 C    OUTPUT WRITE AND FORMAT STATEMENTS
746 - 554.000 C
747 - 555.000 C
748 - 556.000      IF(AFT.GT.0.) WRITE(108,959)
749 - 557.000      IF(AFT.GT.0.) G9 T9 121
750 - 558.000      WRITE(108,960)
751 - 600.000      121 WRITE(108,901)BXID,FUEL,9START,FSTART,9SHUT,FSHUT,FEEDS,
752 - 601.000      9FEEDF,9CHILL,FCHILL,9ENG,FENG,FBIAS,9DRAIN,FDRAIN,9PRESS,
753 - 602.000      9FPRESS,9M9XL,N9MFUL,9ALL9,FALL9W,MAX9XL,MAX9FUL,9BEL9W,
754 - 603.000      9FREL9,MAX9IT,MAX9FIT,9XV9L,FJVL9,T9VFL,TFVFL,DIS9VF,T9VFL
755 - 604.000      9,TFVIT
756 - 605.000      WRITE(108,902)
757 - 606.000      IF(3L<40.EQ.1.)WRITE(108,903)
758 - 607.000      IF(3L<40.EQ.2.)WRITE(108,904)
759 - 608.000      IF(3L<40.EQ.3.)WRITE(108,905)
760 - 609.000      WRITE(108,906)L,D,L80,R,HR
761 - 610.000      IF(3L<40.GT.2.) G9 T9 40
762 - 611.000      WRITE(108,907)NR,9R,9D,H9R,H9S
763 - 612.000      40 WRITE(108,908)ND,THETA,HC,LC9N,H9,HH,K,LA,UPERS,UPERF,
764 - 613.000      9XVLF,FUVLF
765 - 614.000      WRITE(108,950)
766 - 615.000      IF(3L<40.EQ.1.) G9 T9 110
767 - 616.000      G9 T9 111
768 - 617.000      110 IF(49.GT.44) G9 T9 114
769 - 618.000      WRITE(108,951)
770 - 619.000      G9 T9 120
771 - 620.000      111 IF(3L<40.EQ.3.) G9 T9 112
772 - 621.000      G9 T9 113
773 - 622.000      112 WRITE(108,955)
774 - 623.000      113 IF(49.GT.44) G9 T9 115
775 - 624.000      WRITE(108,953)
776 - 625.000      G9 T9 120
777 - 626.000      114 WRITE(108,952)
778 - 627.000      G9 T9 120
779 - 628.000      115 WRITE(108,954)
780 - 629.000      120 WRITE(108,956)890GRP,T9TPS,FWDTK,FAIRT,FWDBLF,FCCTPS,
781 - 630.000      9CONSC,T9SIN,CYLSCT,ACYDM,AFTBLE,WINT,PR9SYS,AFTN4,
782 - 631.000      9FEOSYS,FWDBLA,PRSVNT
783 - 632.000      WRITE(108,957)AFTCYL,SUMP,AFTBLA,RNPU,TWINT,N9SFAR,
784 - 633.000      9AVIGN,9MRPNL,WRETR9,TJNNEL,MISC,BAFF,SUBDRY
785 - 634.000      WRITE(108,958)SUBDRY,GU,DRYWT,RESIDT,UNDRAN,FEEDTR,
786 - 635.000      9PRSURT,FBIAS,INERT,PR9PB,GROSSW,LAMBDA
787 - 636.000      G9 T9 30

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**TABLE 4.20-1**  
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[illegible]

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R43 - 762.000	5//2X,'L9AD ALLBANCE='
R50 - 763.000	5,F4.2,4X,'L9X ULLAGE='F4.2,4X,'LH2 ULLAGE='F4.2//
R51 - 764.000	52X,'L9X TANK VOLUME='F8.0,' FT3 LH2 TANK VOLUME='F8.0
R52 - 765.000	5,' FT3')
R53 - 766.000	950 FORMAT('1',18X,'EXTERNAL TANK WEIGHT SUMMARY')
R54 - 767.000	951 FORMAT(20X,'COMMON BULKHEAD-L9X FWD')
R55 - 768.000	952 FORMAT(20X,'COMMON BULKHEAD-L9X AFT')
R56 - 769.000	953 FORMAT(20X,'SEPARATE BULKHEAD-L9X FWD')
R57 - 770.000	954 FORMAT(20X,'SEPARATE BULKHEAD-L9X AFT')
R58 - 771.000	955 FORMAT(10X,'ALTERNATE FWD SECTION(WITHOUT NOSE FAIRING)')
R59 - 772.000	956 FORMAT(23X,'WEIGHT',26X,'WEIGHT'/24X,'-LB.',28X,'-LB.'//
R60 - 773.000	52X,'BODY GROUP',9X,'',F8.0,' '
R61 - 774.000	52X,'IND. ENVIRN. PRPT.',F8.0,' '
R62 - 775.000	53X,'FWD TANK',10X,'',F8.0,' '
R63 - 776.000	53X,'NOSE FAIRING',7X,F8.0//
R64 - 777.000	54X,'FWD BULKHEAD',6X,F8.0//
R65 - 778.000	55X,'FWD CONE & CYL.',4X,F8.0//
R66 - 779.000	54X,'CONICAL SECTION',F8.0//
R67 - 780.000	55X,'INTER TANK',9X,F8.0//
R68 - 781.000	54X,'CYLINDRICAL SECT.',F8.0//
R69 - 782.000	55X,'AFT CYL & CONE',5X,F8.0//
R70 - 783.000	54X,'AFT BULKHEAD',6X,F8.0//
R71 - 784.000	53X,'INTER TANK SECT.',F8.0,' '
R72 - 785.000	52X,'PROPELLANT SYSTEMS',F8.0,' '
R73 - 786.000	53X,'AFT TANK',10X,'',F8.0,' '
R74 - 787.000	53X,'FEED SYSTEM',9X,F8.0//
R75 - 788.000	54X,'FWD BULKHEAD',6X,F8.0//
R76 - 789.000	55X,'PRESS. AND VENT',5X,F8.0//
R77 - 790.000	957 FORMAT(4X,'CYLINDRICAL SECT.',F8.0//
R78 - 791.000	55X,'SUMPS & VORTEX CTL',F8.0//
R79 - 792.000	54X,'AFT BULKHEAD',6X,F8.0//
R80 - 793.000	55X,'PNEUMATIC & PU SYS',F8.0//
R81 - 794.000	53X,'RRH/STR/TANK ATT.',F8.0,' '
R82 - 795.000	53X,'NOSE FAIRING',6X,'',F8.0,' '
R83 - 796.000	52X,'AVIONICS',11X,'',F8.0,' '
R84 - 797.000	53X,'UMBILICAL PANEL',F8.0,' '
R85 - 798.000	52X,'DEBRIT SYSTEM',5X,'',F8.0,' '
R86 - 799.000	53X,'TUNNEL',12X,'',F8.0,' '
R87 - 800.000	52X,'MISCELLANEOUS',6X,'',F8.0,' '
R88 - 801.000	53X,'APPLES-L9X',7X,'',F8.0,' '
R89 - 802.000	51X,'-----'
R90 - 803.000	534X,'SURTOTAL DRY WEIGHT',F9.0//
R91 - 804.000	958 FORMAT(19X,'SURTOTAL DRY WEIGHT',F9.0//
R92 - 805.000	519X,'GROWTH/UNCERTAINTY',F8.0,' '
R93 - 806.000	518X,'-----'
R94 - 807.000	519X,'DRY WEIGHT',9X,F8.0//
R95 - 808.000	519X,'RESIDUAL PROPELLANT',F8.0,' '
R96 - 809.000	520X,'TANK UNPAVABLE',3X,F8.0//
R97 - 810.000	520X,'FEEDLINE TRAPPED',3X,F8.0//
R98 - 811.000	520X,'PRESSURANT',9X,F8.0//
R99 - 812.000	520X,'PU RIAS',12X,F8.0//
000 - 813.000	518X,'-----'
001 - 814.000	512X,'INERT WEIGHT',7X,F9.0//
002 - 815.000	519X,'USABLE PROPELLANT',F9.0,' '
003 - 816.000	518X,'-----'
004 - 817.000	512X,'TOTAL GROSS WEIGHT',F9.0//
005 - 818.000	510X,'LAMHDA-WRSP/WGRSS='F8.4)
006 - 819.000	959 FORMAT('1',18X,'EXTERNAL TANK PROPELLANT INVENTORY'//
007 - 820.000	510X,'ITEM',23X,'LH2',15X,'L9X'//
008 - 821.000	960 FORMAT('1',18X,'EXTERNAL TANK PROPELLANT INVENTORY'//
009 - 822.000	510X,'ITEM',23X,'L9X',15X,'LH2'//
010 - 931.000	STOP
011 - 932.000	END



## 5. BOOSTER MODULE

5.0 The Booster Vehicle Module contains the analytical and empirical weight estimation relationship necessary to completely define the Solid Rocket Motor (SRM) Booster system. Figure 5-1 depicts a typical recoverable Shuttle SRM and serves to illustrate the detail accounted for in this module. The approach adopted for in this module was to use current applicable data from other contractors. A typical example of this was the analytical work deriving the weight of the basic SRM documented by Kimble of the Aerospace Corporation (Reference M) in 1966. These data were reviewed and additional scaling laws developed to meet current as well as projected requirements, thus reflecting the current state of the art throughout the solid propulsion industry. All scaling equations were developed analytically where possible, and correlated with empirical and point design data to determine the coefficients, exponents and constants required to produce reasonable results. This process consists of (1) comparison of subsystem weights predicted by the theoretical equations with actual and point design data, (2) modification of elements of the theoretical equations to improve the correlation, (3) determination of best curve fits, and (4) evaluation of the correlation to determine the acceptability of the errors resulting from using the best curve fits. Every attempt was made to simplify and reduce the number of equations, expand the range of parametric values and, at the same time, retain the accuracy required for preliminary design studies.

While the results have been quite satisfactory, it will be necessary to update the model as the design progresses and, perhaps, modify or redevelop certain equations. For example, design considerations that have come to light since the Shuttle proposal are water impact beef-up, dynamic pressure at reentry, stress corrosion, and biaxial stress allowables. These changes can be accomplished and incorporated in the model by simply adjusting either the coefficients or constants of each subsystem, or by adding an additional fixed constant. An alternate method would be to shift mass fraction versus propellant curves generated from the present model so that the appropriate curve goes through a known design point. The tendency to use weight estimating techniques beyond their limits is ever present; therefore, attention should be given to the limitations of these equations, so that modifications may be made if the range of the parameters encompassed by the empirical data used in the correlation analysis is exceeded. Table 5-1 presents a complete list of the equations employed in the SRM model.

FIGURE 5-1 SRM STAGE INBOARD PROFILE

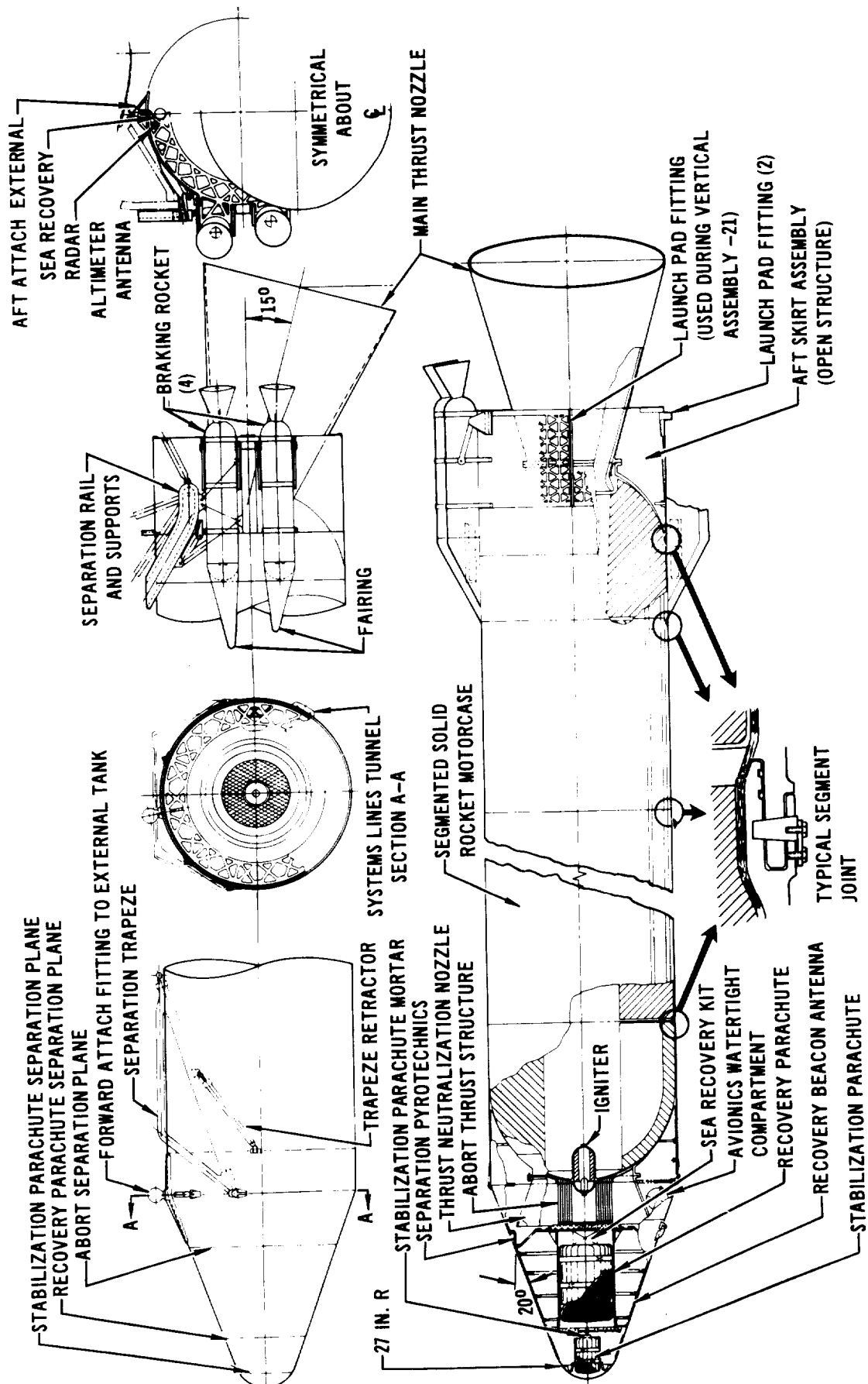




TABLE 5-1  
SUMMARY OF SRM WEIGHT EQUATIONS

COMPONENT	EQUATION
BASIC SRM CASE	$W_c = 11.16 \left[ \rho_m \left( \frac{W_p}{\rho_p \eta_p} \right)^{0.95} \frac{(MEOP)^{0.7} (FS)^{0.7}}{(F_{tu})^{0.9}} \left( \frac{L}{D} \right)^{\frac{(0.163 \frac{b}{a} - 0.114)}{0.315}} \right]^{1.013}$
JOINTS	$W_j = 7.7 D^2 \frac{(MEOP) (FS) N_j}{F_{tu}}$
NOZZLE	$W_{noz} = 0.003505 K_{gn} \left[ \frac{T_b^{0.6} F_{sl}^{1.2} \epsilon^{0.7}}{C_f^{1.2} p_c^{0.8} \left( \tan \frac{\theta}{2} \right)^{0.4}} \right]^{0.916}$
THRUST TERM	$W_{tt} = 0.03518 \left( \frac{F_{sl}}{C_f P_c} \right)^{1.45}$
INSULATION CASE	$W_{ins} = 0.000602 \left[ \left( \frac{W_p}{\rho_p \eta_p} \right)^{0.8} \frac{T_b^{0.5} p_c^{0.117} \left( \frac{T_c}{1000} \right)^{2-0.86}}{\left( \frac{L}{D} \right)^{0.1} (T_{des})^{0.2}} \right]$
JOINTS	$W_{ji} = 2 W_{ij} N_j \text{ OR } W_{ji} = (W_{ui} + W_{ii}) N_j \text{ or } W_{ji} = 2 W_{ui} N_j$
WHERE	
	$W_{ui} = 0.00054 (D - D_p) D T_b$
	$W_{ii} = 0.000178 (D - D_p) [(2D + D_p) T_b + 80 D]$
	$D_p = \left[ \left( \frac{A_p}{A_t} \right) \frac{4 F_{sl}}{\pi C_f P_c} \right]^{1/2}$
EXPENDED	$W_{ei} = 0.005 (W_p); \text{ INCLUDED IN } W_{ins} + W_{ji}$
IGNITER	$W_{ign} = 0.33658 D^{1.45}$
LANDING AND RECOVERY	
PARACHUTE	$W_{par} = 175 + 498 \frac{W_{bo}}{(V_{ri})^2}$
PARACHUTE INSTL	$W_{pi} = 0.6916 W_{par}$
RETRO ROCKET	$W_{rr} = 0.0819 W_{bo} \left( \frac{V_{ri} - V_{sd}}{I_{sp}} \right)$
PROPELLANT	$W_{rp} = 0.675 W_{rr}$
WATER RECOVERY HARDWARE	$W_{wr} = 380$
BODY	
FORWARD SKIRT	$W_{fs} = 13.65 D$
AFT SKIRT/LAUNCH STRUCT	$W_{asls} = 0.00464 \left[ \frac{0.10 W + 2 W_{lo} + 0.65 F_{osl} \cos \phi (L_f + \frac{D}{2})}{4 + D} \right]$
ATTACH/SEP STRUCT	$W_{as} = 952 \frac{F_{sl}}{W_{bo}}$
NOSE FAIRING	$W_{nf} = 0.0607 D^2$
TUNNEL	$W_t = 0.114 L$
OTHER	
AVIONICS	$W_{av} = 182$
TPS	$W_{tp} = 0.018 D^2$

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## 5.1 Subsystem Weight Equations

5.1.1 Basic SRM - The following group of equations represents about 75 percent of the total dry weight.

5.1.2 Case - The equation for an unsegmented metal propellant case is from Reference (M). Its derivation was based on a pressure vessel design assuming a cylindrical case with hemispherical domes.

The thicknesses of the cylinder and dome are:

$$T_{\text{cyl}} = \frac{\text{MEOP}(D)FS}{2F_{tu}}; T_{\text{dome}} = \frac{\text{MEOP}(D)FS}{4F_{tu}}$$

Weights of the cylinder and dome are:

$W_{\text{cyl}} = A_{\text{cyl}} (T_{\text{cyl}}) \rho_m$ ;  $W_{\text{dome}} = A_{\text{dome}} (T_{\text{dome}}) \rho_m$  for hemispherical domes  
where  $A_{\text{cyl}}$  and  $A_{\text{dome}}$  are surface areas of the cylinder and dome respectively.  
 $W_{\text{dome}}$  was modified to account for elliptical domes. Figure 5.1-1 shows the ratio

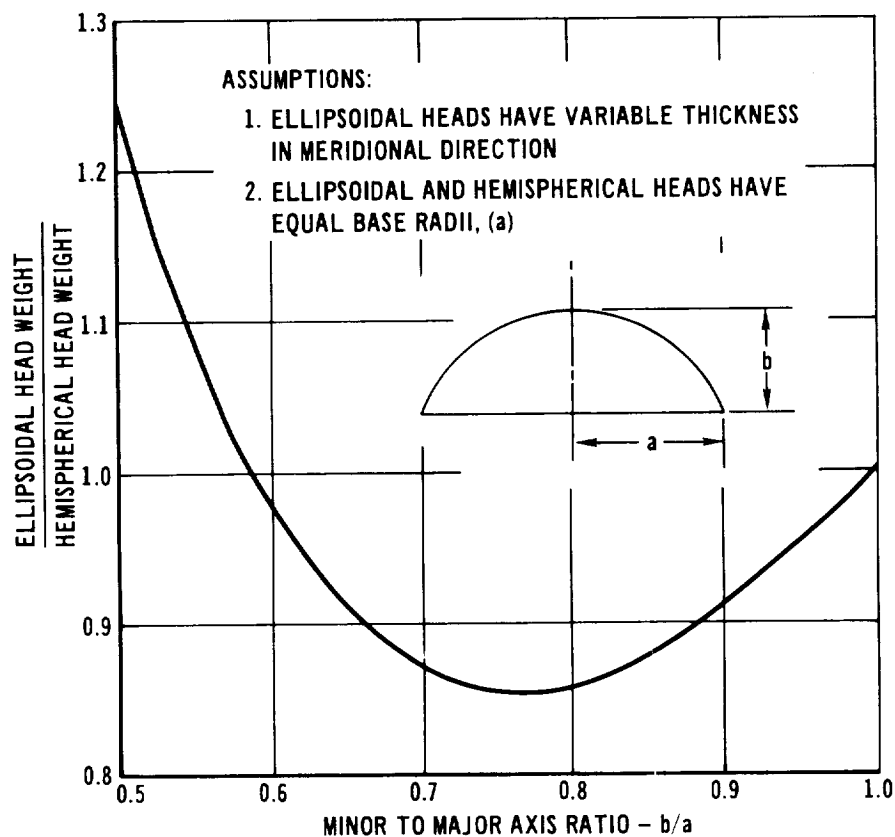


FIGURE 5.1-1 WEIGHT RATIO OF ELLIPSOIDAL TO HEMISPHERICAL DOMES

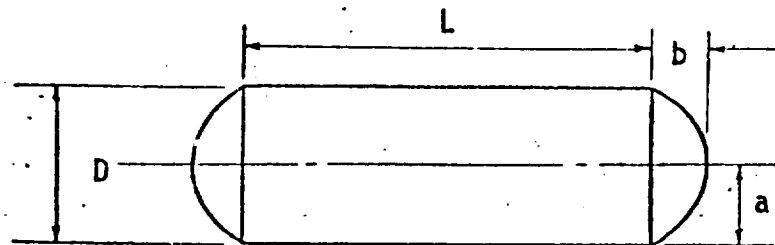
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of the weights of ellipsoidal to hemispherical domes having equal base radii as a function of the ellipse axis ratio (b/a). The following function was derived to fit this curve:

$$\left| \frac{b}{a} - 0.77 \right|^{1.3} + 0.856$$

and case geometry becomes



Substituting equations for thickness, weights of the cylinder and ellipsoidal dome are:

$$W_{cyl} = \frac{\pi D^3 (MEOP) (FS) \rho_m \left(\frac{L}{D}\right)}{2 F_{tu}}$$

$$W_{dome} = \frac{\pi D^3 (MEOP) (FS) \rho_m}{8 F_{tu}} \left[ \left( \left| \frac{b}{a} - 0.77 \right| \right)^{1.3} + 0.856 \right] ; \text{ for one dome}$$

Case volume is

$$V_{case} = \frac{\pi D^3}{2} \left[ \frac{1}{3} \left(\frac{b}{a}\right) + \frac{1}{2} \left(\frac{L}{D}\right) \right] = \frac{W_p}{\eta_p \rho_p}$$

Solving for  $D^3$

$$D^3 = \frac{2 W_p}{\rho_p \eta_p \pi \left( \frac{1}{3} \left(\frac{b}{a}\right) + \frac{1}{2} \left(\frac{L}{D}\right) \right)}$$

Case weight can be expressed as

$$W_c = W_{cyl} + 2 W_{dome} = \frac{MEOP (FS) \rho_m W_p}{F_{tu} (\rho_p) \eta_p} K_g$$

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where

$$K_g = \left[ \frac{\frac{L}{D} + \frac{1}{2} \left( \left| \frac{b}{a} - .77 \right| \right)^{1.3} + 0.856}{\frac{1}{3} \left( \frac{b}{a} \right) + \frac{1}{2} \left( \frac{L}{D} \right)} \right]$$

which is approximated within 5% by

$$K_g = \left[ \frac{1.77 \left( \frac{L}{D} \right) (0.163 \frac{b}{a} - 0.114)}{\left( \frac{b}{a} \right)^{0.315}} \right]$$

The theoretical case weight was then correlated with 20 metal case data points including actual hardware, design studies, and proposals which resulted in the final equation

$$W_c = 11.16 \left[ \left( \frac{W_p}{\rho_p \eta_p} \right)^{0.95} \frac{(MEOP)^{0.7} (FS)^{0.7}}{(F_{tu})^{0.9}} \frac{\left( \frac{L}{D} \right) (0.163 \frac{b}{a} - 0.114)}{\left( \frac{b}{a} \right)^{0.315}} \rho_m \right]^{1.013}$$

Limitations of this equation are listed in Case Segmentation.

Propellant Load Fraction ( $\eta_p$ ) - The weight of star pattern propellant in both domes with a density of 0.063 lb/in<sup>3</sup> was determined to be 70,000 lb for a 156-in. diameter SRM. The volume of the domes and the propellant in them are

$$V_{dome} = \frac{\pi}{6} D^3 \frac{b}{a}; \quad V_{prop} = \frac{70000}{0.063} = 0.559; \quad V_{dome} = 0.292674 D^3 \frac{b}{a}$$

Cylinder length is

$$L = \frac{V_{pc}}{(A_{cs} - A_p)}$$

where the volume of propellant in the cylinder is

$$V_{pc} = \frac{W_p}{\rho_p} - 0.292674 D^3 \frac{b}{a}$$

and case internal cross sectional area is

$$A_{cs} = \frac{\pi}{4} (D - T)^2$$

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Where T is the cylinder wall thickness + insulation

$$T = \frac{MEOP(D)FS}{2F_{tu}} + 0.25$$

The total case volume for a  $A_p/A_t$  ratio of 1.3 is

$$V_{case} = \frac{\pi}{6} D^3 \frac{b}{a} + \frac{\pi}{4} D^2 \left( \frac{V_{pc}}{A_{cs} - 1.3 A_t} \right)$$

Since the propellant loading fraction is defined as propellant volume divided by case volume

$$\eta_p = \frac{W_p}{\rho_p V_{case}}$$

5.1.3 Case Segmentation - The equation in 5.1.2 is for an unsegmented case, but large SRM's are divided into segments resulting in a joint penalty. Reference (M) provided the source of the equation and derivation used for this penalty. It was assumed that flight and ground handling loads do not design the joint and the joint cross sectional area will vary linearly with case wall thickness. Weight of the joints is

$$W_j = \pi D A_{xj} \rho_j N_j$$

where  $A_{xj}$  is the joint cross sectional area and  $\rho_j$  is the density of the joint material. Since

$$A_{xj} \propto T_{cyl}$$

$$\text{where } T_{cyl} = \frac{(MEOP)FS(D)}{2F_{tu}} \text{ from Paragraph 5.1.2.}$$

$$W_j = \pi D^2 \frac{(MEOP)(FS)(\rho_j)N_j}{2F_{tu}}$$

Assuming that the joints are manufactured from steel,  $\rho_j$  is relatively constant. Removing constants

$$W_j \propto D^2 \frac{(MEOP)(FS)N_j}{F_{tu}}$$

Applying this expression to manufactured joint data, the following weight equation for case joint penalties resulted

$$W_j = 7.7 D^2 \frac{MEOP(FS)N_j}{F_{tu}}$$

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This equation is applicable to pin and clevis type joints only. A set of parametric limits was established for the joint equation as well as the case equation previously presented. They are:

$$3000 < W_p < 2,000,000 \text{ lb}$$

$$500 < MEOP < 1500 \text{ lb/in}^2$$

$$0.25 < L/D < 8$$

$$0.6 < b/a < 1.0$$

The values of the material property parameter  $F_{tu}$  to be used in the equations is room temperature value. It has been assumed that case insulation will prohibit steel cases from exceeding 350°F.

**5.1.4 Case Weight Comparison** - A comparison of proposed 156 in. diameter SRM case weights and predicted case weights resulting from equations in Paragraphs 5.1.2 and 5.1.3 is presented in Table 5.1-1. Proposed weights and design parameters were obtained from SRM study reports submitted to NASA by Lockheed, Aerojet, UTC, and Thiokol on 15 March 1972. Biaxial gain was accounted for by either a lower FS or a higher  $F_{tu}$  in the SRM proposals which took advantage of it. The reported case weights were 5 to 13 percent lower than those predicted by the parametric equations.

**5.1.5 Nozzle** - The nozzle weight equation from Reference (M) was for a fixed ablative nozzle divided into seven sections as shown in Figure 5.1-2. Based on the analysis of the section theoretical weight equations, a single parametric weight estimating proportionality expression was derived.

$$W_{noz} \propto \frac{(W_p C^*)^{1.2} \epsilon^{0.65}}{P_c^{0.6} T_b^{0.5} (\tan \frac{\theta}{2})^{0.5}}$$

This expression provided the basis for the correlation analyses which resulted in the final equation

$$W_{noz} = 0.0000772 K_{gn} \left[ \frac{(W_p C^*)^{1.2} \epsilon^{0.7}}{P_c^{0.8} T_b^{0.6} (\tan \frac{\theta}{2})^{0.4}} \right]^{0.916}$$

TABLE 5.1-1  
COMPARISON OF PROPOSED SRM CASE WEIGHTS WITH THOSE  
PREDICTED BY AEROSPACE EQUATION

SRM REPORT	PROPELLANT $W_p$ (LB)	PROPELLANT DENSITY $\rho_p$ (LB IN. <sup>3</sup> )	PROPELLANT LOADING FACTOR $\gamma_p$	MAX OP PRESSURE MEOP (PSI)	F.S.	ULTIMATE STRENGTH $F_{tu}$ (KSI)	MATERIAL DENSITY $\rho_m$ (LB IN. <sup>3</sup> )	MATERIAL	DIAMETER D (IN.)
LOCKHEED	1,231,031	0.0649	0.76397	1000	1.4	225 <sup>①</sup>	0.283	D6AC	156
AEROJET	100,000	SEE NOTE <sup>④</sup>		1000	1.4	220 <sup>②</sup>	0.283	D6AC	156
UTC	1,250,000	0.0635	0.78082	1000	1.25 <sup>③</sup>	195	0.283	D6AC	156
THIOKOL	1,217,664	0.064	0.82335	996	1.4	200	0.283	D6AC	156
MDAC	1,270,000	0.063	0.7914	1000	1.4	225	0.283	D6AC	156

SRM REPORT	L D OF CYLINDER	NUMBER OF JOINTS $N_j$	PREDICTED CASE WEIGHT (EQUATIONS)			PROPOSED CASE WT (LB)	PREDICTED WEIGHTS ( ) % HIGHER THAN PROPOSED
			UNSEGMENTED $W_c$ <sup>⑤</sup>	JOINTS $W_j$ <sup>⑥</sup>	TOTAL (LB)		
LOCKHEED	7.66	8	91,034	9328	100,362	95,373	( 5.3 )
AEROJET	5.61	3	69,282	3577	72,859	69,030	( 5.5 )
UTC	7.79	4	197,791	4805	112,596	99,799	(12.8)
THIOKOL	7.08	4	104,179	5226	109,405	102,755	( 6.5 )
MDAC	7.88	7	103,605	8162	111,767	103,206	( 8.3 )

NOTES: <sup>①</sup> BIAxIAL ULTIMATE STRENGTH = 254 KSI FOR 13% GAIN

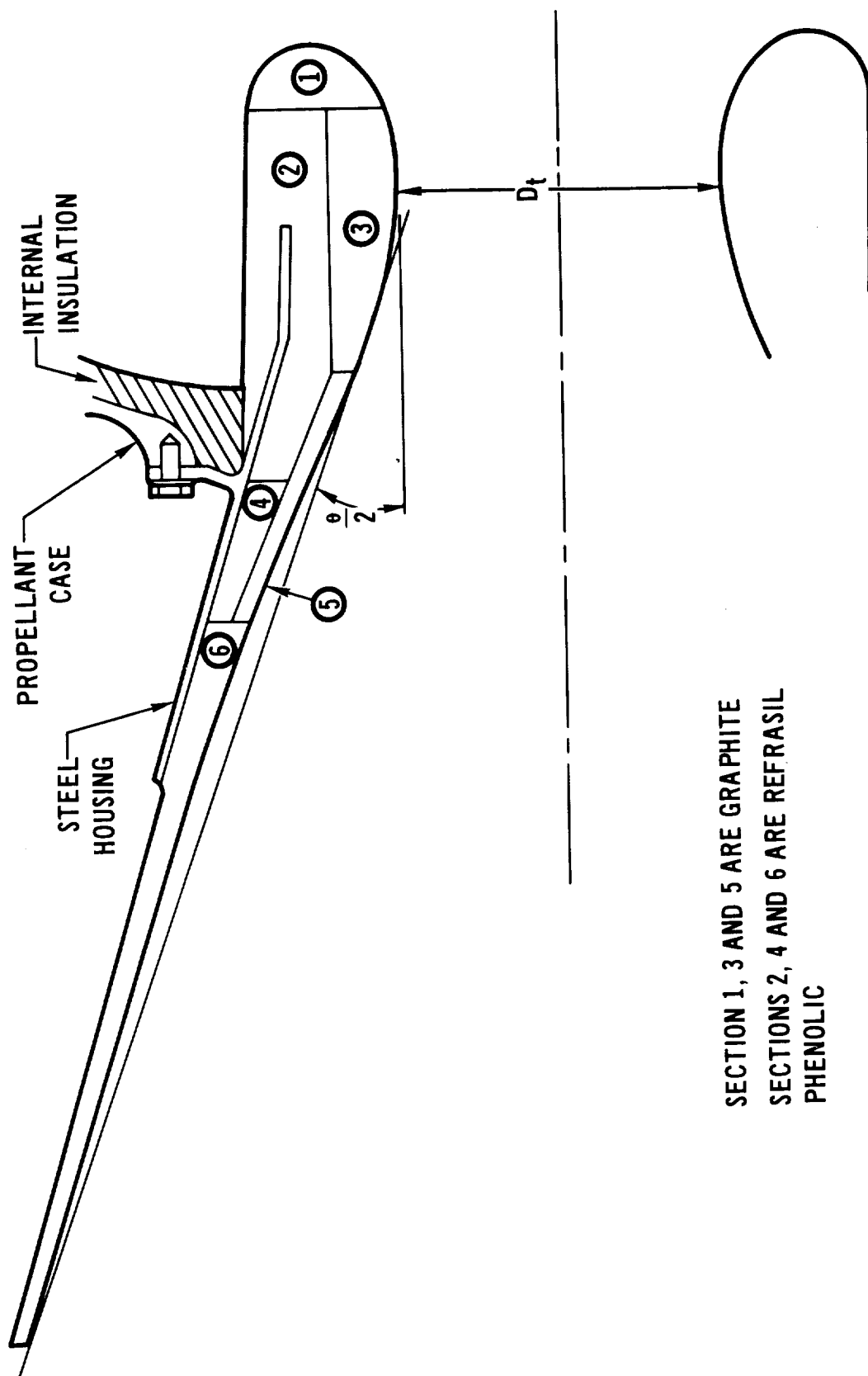
<sup>②</sup> BIAxIAL ULTIMATE STRENGTH = 248 KSI FOR 13% GAIN

<sup>③</sup> F.S. SHOWN IS FOR UNIAxIAL TENSILE STRENGTH. ACTUAL BREAKING STRENGTH OF A CASE WITHOUT IMPERFECTIONS IS UP TO 15% GREATER THAN THE DESIGN BURST PRESSURE DUE TO THE APPARENT INCREASE IN MATERIAL STRENGTH IN A BIAxIAL STRESS FIELD.

<sup>④</sup> THIS DATA NOT AVAILABLE

$$\supseteq W_c = 11.16 \left[ \left( \frac{W_p}{P_p \eta_p} \right)^{0.95} \frac{(MEOP \cdot FS)^{0.7}}{(F_{tu})^{0.9}} \left( \frac{L}{D} \right)^{0.049} P_m \right]^{1.013}$$

$$\supseteq W_j = 7.7 (D)^2 \frac{MEOP \cdot FS \cdot N_j}{F_{tu}}$$



SECTION 1, 3 AND 5 ARE GRAPHITE  
SECTIONS 2, 4 AND 6 ARE REFRASIL  
PHENOLIC

FIGURE 5.1-2 NOZZLE ANALYTICAL MODEL



which is equivalent to

$$W_{noz} = 0.003505 K_{gn} \left[ \frac{T_b^{0.6} F_{sl}^{1.2} \epsilon^{0.7}}{C_f^{1.2} P_c^{0.8} (\tan \frac{\theta}{2})^{0.4}} \right]^{0.916}$$

where  $K_{gn} = \frac{2.1}{\epsilon}$  for gimballed nozzles and 1.0 for fixed nozzles. The

following limits apply to the ablative nozzle weight scaling equation

$$500 < W_p < 2,000,000 \text{ lb}$$

$$30 < T_b < 140 \text{ sec}$$

$$300 < P_c < 1000 \text{ lb/in}^2$$

$$5 < \epsilon < 75$$

$$15 < \theta/2 < 30 \text{ deg}$$

Thrust Termination - Thrust termination provides a negative or zero thrust so the port area must be related to the nozzle throat area. From Reference (M)

$$W_{tt} \propto \frac{W_p C^*}{P_c T_b} \propto \frac{F_{sl}}{C_f P_c}$$

and correlation of  $\frac{W_p}{P_c T_b}$  with thrust termination weights resulted in

$$W_{tt} = 170 \left( \frac{W_p}{P_c T_b} \right)^{1.45}$$

However, the constant was changed to reflect a point design so the final equation is

$$W_{tt} = 0.03518 \left( \frac{F_{sl}}{C_f P_c} \right)^{1.45}$$

5.1.6 Insulation - The source for internal insulation weight equations was Reference (M).

$$W_{ins} = 0.000602 \left[ \left( \frac{W_p}{\rho_p \eta_p} \right)^{0.8} \frac{T_b^{0.5} P_c^{0.117} \left( \frac{T_c}{1000} \right)^2}{\left( \frac{L}{D} \right)^{0.1} (T_{des})^{0.2}} \right]^{0.86}$$

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Additional insulation required for joints is

$$W_{ui} = 0.00054 (D - D_p) D T_b$$

or

$$W_{ii} = 0.000178 (D - D_p) [(2D + D_p) T_b + 80D]$$

where

$$D_p = \left[ \left( \frac{A_p}{A_t} \right) \left( \frac{4W_p C^*}{\pi P_c T_b g} \right) \right]^{1/2} = \left[ \left( \frac{A_p}{A_t} \right) \frac{4F_{sl}}{\pi C_f P_c} \right]^{1/2}$$

For both propellant segment ends inhibited from burning (inhibiting function is accomplished with insulation)

$$W_{ji} = 2W_{ii} N_j$$

If one end is inhibited

$$W_{ji} = (W_{ui} + W_{ii}) N_j$$

If neither end is inhibited

$$W_{ji} = 2W_{ui} N_j$$

The following set of limits represent the range of parameters in the empirical data:

$$2000 < W_p < 3,000,000 \text{ lb}$$

$$40 < T_b < 140 \text{ sec}$$

$$300 < P_c < 1200 \text{ lb/in}^2$$

$$5000 < T_c < 6500^\circ\text{F}$$

$$0.25 < L/D < 8$$

Expended insulation from  $W_{ins}$  and  $W_{ji}$  during burn time was estimated to be

$$W_{exins} = 0.005 W_p$$

5.1.7 Igniter - Igniter weight of some SRM's was plotted versus motor diameter with the resulting equation of the curve being

$$W_{ign} = 0.376 D^{1.45}$$

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5.2 Landing and Recovery - These equations predict weight for parachute and braking rocket systems. Figure 5.1-3 presents the recovery mode for the point design which was used as the basis in determining equation parameters and coefficients.

5.2.1 Parachute - A retro rocket ignition velocity of 240 ft/sec and SRM burnout weight of 188,000 lb were used in the analysis of the parachute system. The following weight summary indicates what components were included:

## PARACHUTE HARDWARE LIST AND WEIGHT SUMMARY

<u>DESCRIPTION</u>	<u>WEIGHT - LB</u>
STABILIZATION PARACHUTE SUBSYSTEM	
Stabilization Chute, 23.0 ft ( $D_o$ ) 23° Conical Ribbon	90
Riser, 25.6 ft long, suspension lines continued	17
Deployment Bag	9
Mortar, 20 in. dia. x 32 in. deep	36
Cartridge, uses 2 SBASI for initiation	1
Nose Cap, held by shear pins until mortar force	18
Bridle, tie between nose cone and pilot bag	<u>4</u>
	175
MAIN PARACHUTE SUBSYSTEM	
Pilot Chute, 13.7 ft ( $D_o$ ) 25° Conical Ribbon	9
Riser, 56.3 ft long	16
Deployment Bag, Pilot	1
Main Chute, 78.5 ft ( $D_o$ ) 20° Conical Ribbon	1464
Deployment Bag, Main	127
Reefing Line Cutter, 10 sec delay (4 required)	2
Reefing Line, 9000 lb MIL-W-4088, 129 ft long	9
Explosive Bolt, release for attachment ring	2
Jumper Line, attach ring to flotation and retrieval gear	<u>1</u>
	1631

It was assumed that the stabilization parachute subsystem weight remains constant. The main parachute weight equation was derived from the fact that

$$W_{bo} = C_d A_p q$$

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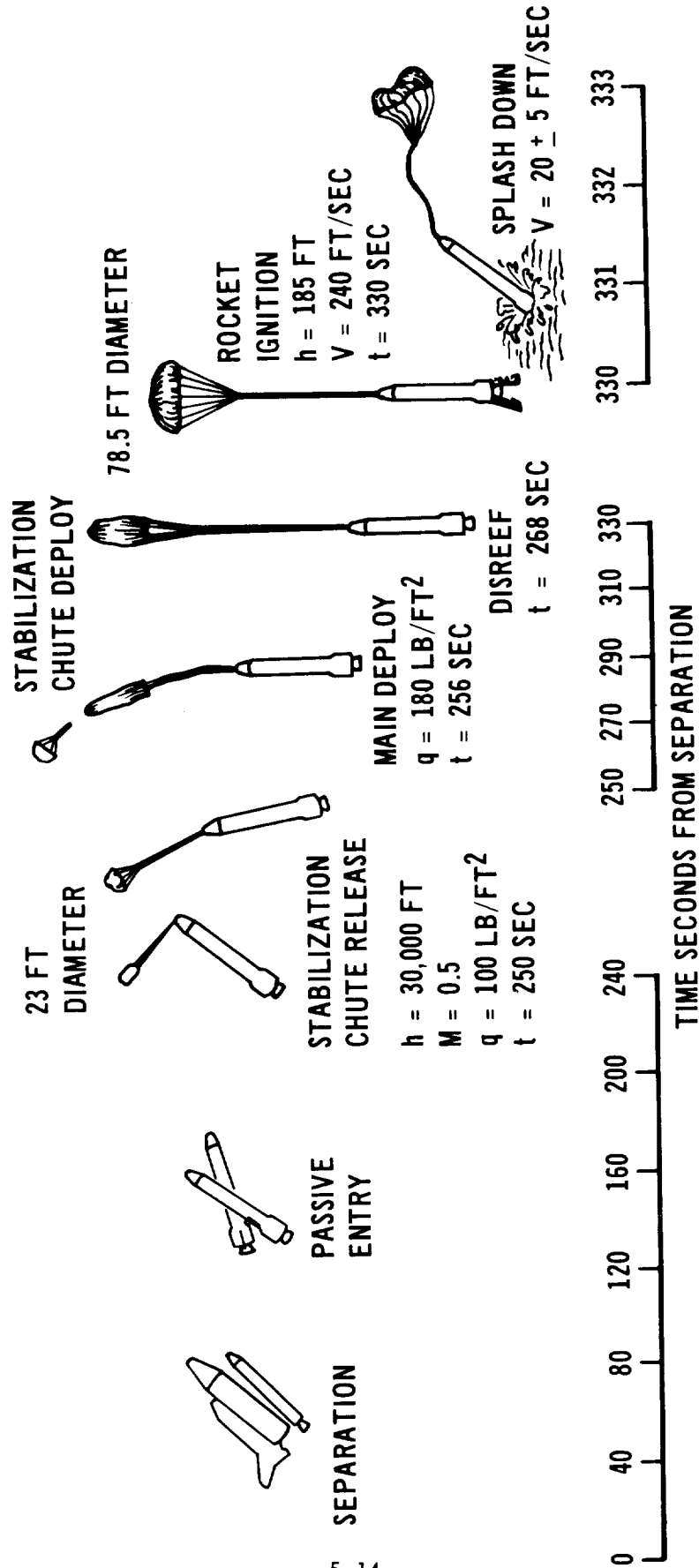


FIGURE 5.1-3 SRM STAGE RECOVERY MODE

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where  $C_d$  is the drag coefficient,  $A_p$  the parachute area, and  $q$  the aerodynamic pressure which can be expressed as

$$q = 1/2 \rho_a V^2$$

where  $\rho_a$  is atmospheric density at altitude and  $V$  is velocity. Assuming that parachute weight is proportional to area,  $C_d$  constant, and  $\rho_a$  constant

$$W_{par} \propto \frac{W_{bo}}{(V_{ri})^2}$$

The total parachute system weight equation is

$$W_{par} = 175 + 498 \frac{W_{bo}}{(V_{ri})^2}$$

Parachute Installation - A summary of installation hardware compatible with the parachute system follows:

## PARACHUTE INSTALLATION HARDWARE LIST AND WEIGHT SUMMARY

<u>DESCRIPTION</u>	<u>WEIGHT - LB</u>
ACCESSORY HARDWARE	
Support Ring	680
Severance Ring	48
Linear Shaped, Charge Assembly	21
Foam Filler (for flotation), 32 ft <sup>3</sup>	128
Support Bulkhead	65
Flotation Bag, Pressurization Vessel and Valve	40
Cannister	185
Attachment Ring, 80 suspension lines, 4 each at 20 points	70
Miscellaneous	12
	<u>1249</u>

This hardware is assumed to be proportional to the parachute weight so

$$W_{pi} = 0.6916 W_{par}$$

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5.2.2 Retro Rockets - The characteristics of the point design braking rockets are as follows:

## Braking Rockets

Number	4 per SRM Stage
SL Thrust (lb/rocket)	283,500/35,780 (Boost/Sustainer)
SL Specific Impulse (sec)	249/213 (Boost/Sustainer)
Burn Time (sec)	1.3/5.6 (Boost/Sustainer)
Propellant Wt (lb)	10,104
Gross Wt (lb)	14,968

The total ideal velocity available from the rocket is

$$\Delta V = g I_{sp} \ln \frac{W_{bo}}{W_{bo} - W_{rp}}$$

From a series expansion

$$\ln \frac{W_{bo}}{W_{bo} - W_{rp}} = \frac{W_{rp}}{W_{bo}} + \frac{1}{2} \left( \frac{W_{rp}}{W_{bo}} \right)^2 + \dots$$

Since the retro rocket propellant is only a small portion of the total weight, all terms of the expansion after the first one can be neglected so that

$$W_{rp} = \frac{\Delta V W_{bo}}{g I_{sp}}$$

Assuming a constant mass fraction and that  $(V_{ri} - V_{sd})$  is proportional to burn time

$$W_{rr} \propto \frac{(V_{ri} - V_{sd}) W_{bo}}{I_{sp}}$$

An ignition velocity of 240 ft/sec, water impact velocity of 20 ft/sec, SRM burnout weight of 188,500 lb, and average  $I_{sp}$  of 235 sec were used in the determination of the final equation for rocket weight including attach structure

$$W_{rr} = 0.0819 \frac{(V_{ri} - V_{sd}) W_{bo}}{I_{sp}}$$

The propellant mass fraction is

$$\frac{W_{rp}}{W_{rr}} = 0.675$$

5.2.3 Water Recovery Hardware - The components and weights of this subsystem are summarized as follows:

<u>SRM RECOVERY HARDWARE</u>	
	<u>WEIGHT - LB</u>
Line	120
Mortars	100
Floats	60
Sea Anchors	20
Attach Lugs	80
	<hr/> 380

Since the weight of these items is assumed to remain constant

$$W_{wr} = 380$$

5.2.4 Body - This group includes structural components required for making the basic SRM adaptable to Shuttle use. Weight equations were derived, using a point design as the basis for parameters and coefficients. The equations are adequate for sizing purposes in spite of their simplicity. Considerable analysis beyond the scope of preliminary design presently available would be necessary to increase the degree of confidence in them. As it is, the body group represents only 15 percent of the total SRM dry weight.

Forward Skirt - The design of this item reflects minimum weight structure at a constant length. Weight can be expressed in terms of diameter, so using point design data

$$W_{fs} = 13.65 D$$

Aft Skirt/Launch Structure - Assuming the critical load to be at liftoff with orbiter engines firing and negligible wind effects

$$W_{asls} = \text{axial load} + \text{reaction of orbiter thrust}$$

Distributing the load to two fittings on the open trusswork skirt

$$W_{asls} = \alpha \left[ \frac{OLOW + 2W_{lo}}{4} + \frac{(1.3) \frac{F_{osl}}{2} \cos \phi (L_f + \frac{D}{2})}{D} \right]$$

Where 1.3 is the dynamic amplification factor. From point design data the final equation is

$$W_{asls} = 0.00464 \left[ \frac{OLOW + 2W_{lo}}{4} + \frac{0.65 F_{osl} \cos \phi (L_f + \frac{D}{2})}{D} \right]$$

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Attach/Separation Structure - An equation was derived from a simplified relationship of loads. Structural weight decreases with reduced SRM engine thrust or when a heavier SRM relieves the load. From point design data

$$W_{as} = 952 \frac{F_{sl}}{W_{lo}}$$

Nose Fairing - A constant unit weight resulting from the point design is applied to any nose cone area. For a 20 deg cone

$$W_{nf} = 0.0607 D^2$$

Tunnel - Weight of the systems lines tunnel depends on cylindrical case length

$$W_t = 0.114 L$$

5.3 Other - Weight equations for remaining systems are included in this section.

Avionics - Avionics weight remains constant.

$$W_{av} = 182$$

The following summary indicates the items included

AVIONICS WEIGHT SUMMARY

	<u>WEIGHT - LB</u>
Chamber Pressure Transducers	18
Battery	8
Sequence Control	5
Radar Altimeter	7
Radar Antenna	2
Relays	15
Receiver Antenna	8
Receiver Transmitter	16
Barometric Switches	2
Wiring and Connectors	67
Supports	<u>34</u>
	182

TPS - Nose insulation reflects a constant unit weight material. For a 20 deg cone

$$W_{tp} = 0.018 D^2$$



5.4 SRM Module - The SRM model that has been incorporated into the overall sizing program is in modular form and includes the preceding weight scaling equations. This module provides a desirable weight estimation tool for analyzing the preliminary design studies of point design or, in the ESPER program it provides the capability of optimization of the system by inputting a desired diameter and iterating on propellant load and engine characteristics. The module has built in error messages that tell the user when the limits of the parameter encompassed by the empirical data used in the correlation analysis have been exceeded. It also contains input constant which allows the user to input weight changes without modifying the program. As with the Orbiter and External Tank Modules the flexibility is inherent for replacing relationships or modifying the internal constants with a minimum of effort.

The SRM Module also contains the option of utilizing a simplified equation to derive the SRM weight rather than the detailed analysis. The primary purpose of this option is to save time and money. This is accomplished by greatly reducing the computer run time as well as eliminating the 39 input variables required to run the detailed program. In the formulation of this equation, the primary parameters considered were usable ascent propellant and sea-level thrust. A battery of parametric runs was completed in which sea-level thrust was varied from 3.0M to 5.0M lb and ascent propellant loadings from 1.0M to 2.0M lb SRM burn out weight was then plotted against sea-level thrust resulting in a family of propellant curves as shown in Figure 5.4-1. Each of these curves were analyzed by a least squares curve fit to determine the coefficients of the equations describing them. These resulting coefficients were, in turn, curve-fit to give interpolation capabilities. The resulting equations are as follows:

$$C\emptyset EFSE = 29653.3 + (PR\emptyset PB * 0.0773338)$$

$$BB\emptyset WT = C\emptyset EFSE + (THBSL * 0.01887863)$$

**where:** PROPB = Usable ascent propellant weight.

THBSL = Sea level thrust

Table 5.4-1 is a detail listing of the input parameter both in the symbolic notation as used in the equation formulation and in the Fortran language as is used in the computer program. Included with each parameter is a physical description and the corresponding dimensional units. Figure 5.4-2 depicts a typical SRM with various sections and dimensions noted. The following table (Table 5.4-2 is a data input file

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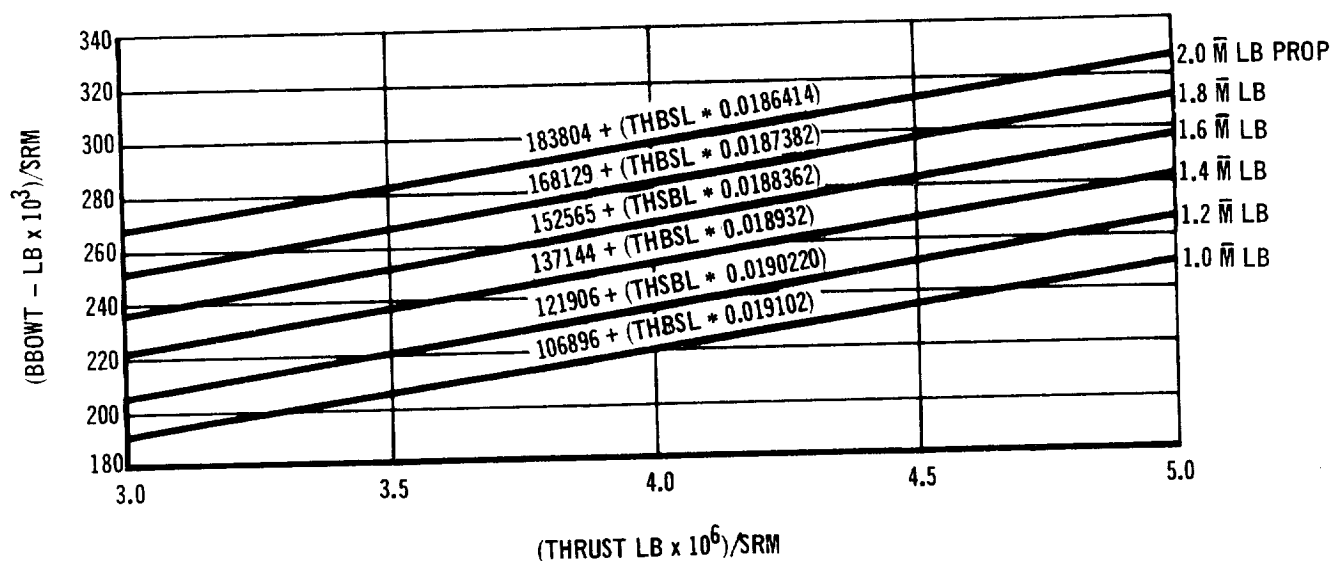


FIGURE 5.4-1 SRM BURNOUT WEIGHT VS SRM SEA LEVEL THRUST

TABLE 5.4-1  
SRM MODULE NOMENCLATURE  
(PER SRM)

VARIABLE NAME		DEFINITION	UNITS
FORTRAN	SYMBOLIC		
MAAX	a	Major axis of ellipsoidal dome	IN.
AP	$A_p$	Propellant grain port area	IN. <sup>2</sup>
AT	$A_t$	Nozzle throat area	IN. <sup>2</sup>
MIAX	b	Minor axis of ellipsoidal dome	IN.
CF	$C_f$	Thrust coefficient	N.D.
DIA	D	Case diameter	IN.
DP	$D_p$	Propellant grain port diameter	IN.
THØSL	$F_{os1}$	Total orbiter sea level thrust	LB
THBSL	$F_{s1}$	SRM sea level thrust	LB

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TABLE 5.4-1  
SRM MODULE NOMENCLATURE (Continued)  
(PER SRM)

VARIABLE NAME		DESCRIPTION	UNITS
FORTTRAN	SYMBOLIC		
FTU	$F_{tu}$	Ultimate tensile strength	lb/in <sup>2</sup>
FS	FS	Factor of safety	N.D.
RRISP	$I_{sp}$	Average specific impulse of retro rocket propellant	SEC
LTH	L	Length of cylindrical portion of case	IN.
LF	$L_f$	Distance from edge of aft skirt end to orbiter thrust line	IN.
MEØP	MEØP	Maximum expected operating pressure	lb/in <sup>2</sup>
NJ	$N_j$	Number of segment joints	N.D.
ØGLØW	ØLØW	Orbiter liftoff weight including external tank	LB
PC	$P_c$	Average operating chamber pressure	lb/in <sup>2</sup>
BBT	$T_b$	SRM burn time	SEC
TC	$T_c$	Combustion temperature	°F
TDES	$T_{des}$	Case design temperature	°F
VRI	$V_{ri}$	Velocity @ retro rocket ignition	FT/SEC
VSD	$V_{sd}$	Velocity @ water impact	FT/SEC
WAS	$W_{as}$	Attach/separation structure weight	LB
WASLS	$W_{asls}$	Aft skirt/launch structure weight	LB
WAV	$W_{av}$	Avionics weights	LB
BBØWT	$W_{bo}$	SRM burnout weight	LB
WCASE	$W_c$	Unsegmented case weight	LB
EXPINS	$W_{ei}$	Expendable insulation weight	LB
WFS	$W_{fs}$	Forward skirt weight	LB
WIGN	$W_{ign}$	Igniter weight	LB
WII	$W_{ii}$	Inhibited segment end insulation weight	LB
WINST	$W_{ins}$	Internal insulation weight	LB
WJØINT	$W_j$	Case segment joint weight	LB
WINSJ	$W_{ji}$	Segment joint insulation weight	LB
BLØWT	$W_{lo}$	SRM liftoff weight	LB
WNF	$W_{nf}$	Nose fairing weight	LB
WNØZZ	$W_{noz}$	Nozzle weight	LB

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TABLE 5.4-1  
SRM MODULE NOMENCLATURE (Continued)  
(PER SRM)

VARIABLE NAME		DEFINITION	UNITS
FORTTRAN	SYMBOLIC		
PRØPB	$W_p$	Propellant weight	LB
WPAR	$W_{par}$	Parachute weight	LB
WPI	$W_{pi}$	Parachute installation weight	LB
WRP	$W_{rp}$	Retro rocket propellant weight	LB
WRR	$W_{rr}$	Retro rocket (including installation) weight	LB
WTN	$W_t$	Tunnel weight	LB
WNCTPS	$W_{tp}$	Nose cone thermal protection weight	LB
WTER	$W_{tt}$	Thrust termination weight	LB
WUI	$W_{ui}$	Uninhibited segment end insulation weight	LB
WWR	$W_{wr}$	Water recovery hardware weight	LB
NER	$\epsilon$	Nozzle expansion ratio	N D
NP	$\eta_p$	Propellant loading fraction	N D
NDHA	$\Theta/2$	Nozzle divergence half angle	DEG
RHØM	$\rho_m$	Case material density	LB/IN. <sup>3</sup>
RHØP	$\rho_p$	Propellant density	LB/IN. <sup>3</sup>
AAØE	$\phi$	Average angle of orbiter engines with X axis in X-Z plane	DEG
INT		Insulation thickness	IN.
BUNC1		Percent uncertainty applied to the Government furnished Eq.'s of the SRM	%
WNØZ		Counter-nozzle type - 0.0 - fixed 1.0 - gimballed	N D
WEI		Counter-joint type - 0.0 - neither end inhibited 1.0 - one end inhibited	N D
BASSRM		Basic SRM weight	LB
UNCERT		Total uncertainty weight	LB
WRECØV		SRM recovery system weight	LB
SRMISS		SRM body adapter weight	LB
BGLØW		SRM gross launch weight	LB
LAMB		SRM LAMBDA	N.D
BSRMC		Basic SRM weight constant	LB
SRMIC		SRM adapter weight constant	LB
SRMRC		SRM recovery weight constant	LB

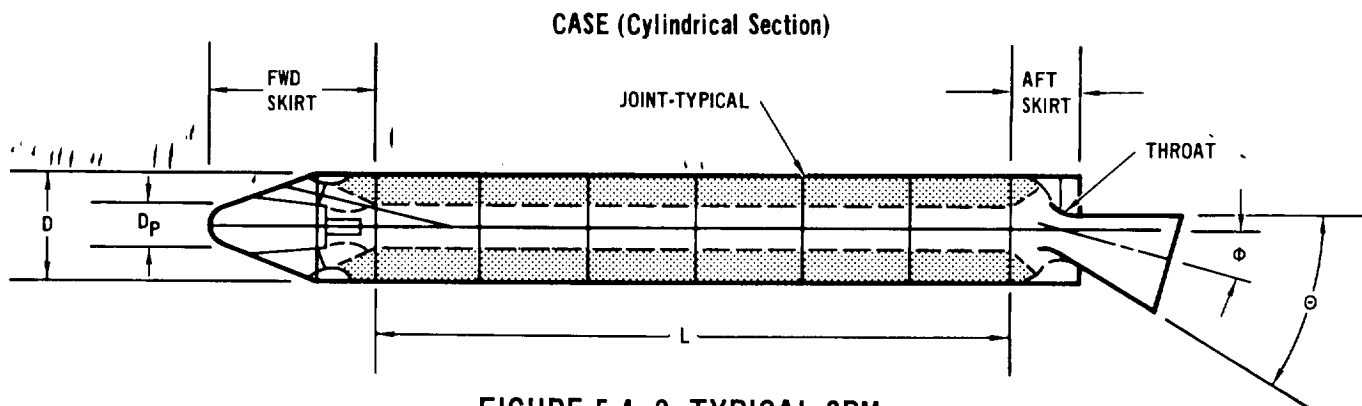


FIGURE 5.4-2 TYPICAL SRM

corresponding to the NR 162-in Booster, followed by the resulting detail printout, Table 5.4-3. Following this is a simplified flow diagram of the module (Figure 5.4-3) and a listing of the computer program (Table 5.4-4).

TABLE 5.4-2  
NORTH AMERICAN BOOSTER DATA FILE

```

1.000  PR0PB=1406167.,RH0P=.065,DIA=162.,M1AX=81.,MAAX=81.
2.000  ME0P=1000.,FS=1.4,F1U=254000.,RH0M=.283,INI=.1
3.000  NP=.76397,NJ=5.,#NOZ=1.,NER=11.2,BRT=125.,AP=3680.0
3.500  TH3SL=3917000.
4.000  CF=1.58,PC=833.3,NDHA=15.,TC=5800.,TDES=250.,AT=2930.
4.500  BB0WT=231890.
5.000  VRI=141.,VSD=141.,03LOW=2000000.,TH0SL=395000.,AA0E=10.
6.000  LF=200.,BUNC1=.035,BUNC2=.035,RRISP=235.,WEI=0.0
7.000  HSRMC=0.0,SRMIC=0.0,SRMRC=3500.
10.000  *
```

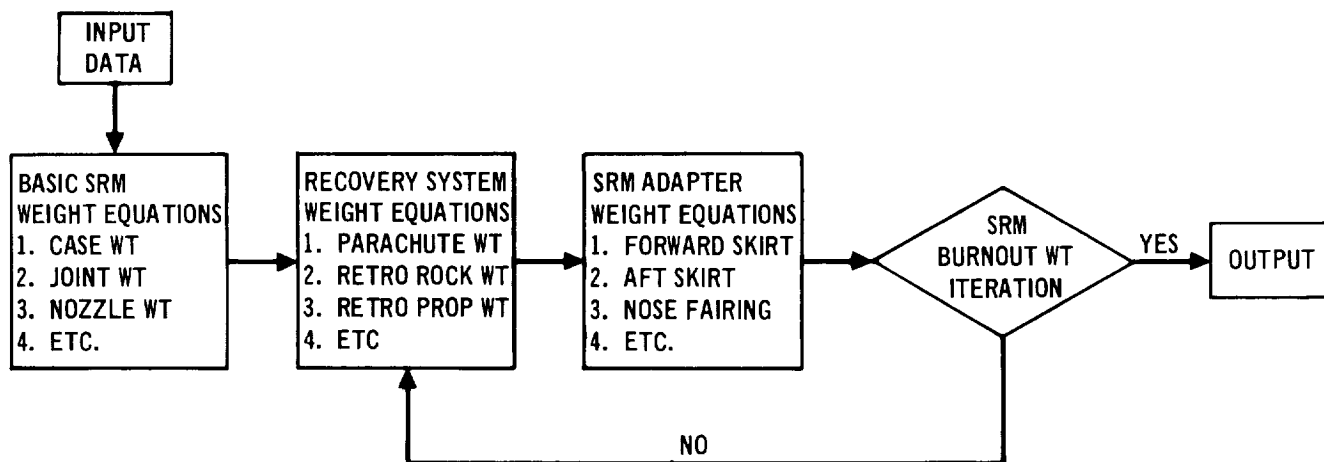


FIGURE 5.4-3 SRM MODULE SIMPLIFIED FLOW DIAGRAM

TABLE 5.4-3  
NORTH AMERICAN BOOSTER PRINTOUT

WEIGHT SUMMARY (PER SRM) - LB.

BASIC SRM WEIGHT	(	167917.)
CASE WEIGHT		102459.
JOINT WEIGHT		5569.
NOZZLE WEIGHT		46803.
THRUST TER WEIGHT		3827.
INSULATION WEIGHT		8721.
IGNITER WEIGHT		538.
BASIC SRM WT. CONST.		0.
SRM RECOVERY WEIGHT	(	13149.)
PARACHUTE WEIGHT		5480.
PARACHUTE INSIL		3790.
RETRO ROCKET		0.
PROPELLANT WEIGHT		0.
WATER REC. HWD.		380.
SRM REC. WT. CONST.		3500.
SRM INTERSTAGE ST.	(	30331.)
FORWARD SKIRT		2211.
AFT SKIRT ST.		8125.
ATTACH/SEP STRUCT		17609.
NOSE FAIRING		1593.
TUNNEL WEIGHT		138.
AVIONICS WEIGHT		182.
TPS WEIGHT		472.
SRM INTERS. CONST		0.
UNCERTAINTY WT.	(	7399.)
EXPENDABLES	(	-7031.)
SRM BURNOUT WEIGHT	(	211765.)
SRM PROP. WEIGHT	(	1406167.)
LAMBDA		.865
SRM GROSS WEIGHT	((	1624962.))

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TABLE 5.4-4  
PROGRAM LISTING

1	*	1.000	*FIXED	
2	*	2.000		IMPLICIT REAL(A,Z)
3	*	3.000		DIMENSION FID(4)
4	*	4.000		NAMLIST PR0PB,RH0P,DIA,MIA,MAAX,ME0P,FS,FTU,AT
5	*	5.000		1,RH0M,INT,NP,NJ,WNRZ,NER,BBT,AP,TH0SL,CF,PC,NDHA
6	*	6.000		2,TC,TDES,BBWT,VRI,VSD,0GL0W,TH0SL,AA0E,LF
7	*	7.000		3,BUNC1,BUNC2,RRISP,WEI,BSRMC,SRMIC,SRMRC
8	*	8.000		CALL EBFSET(99999S)
9	*	9.000		READ 500,FID
10	*	10.000	500	FORMAT(4A4)
11	*	11.000		CALL BPENFS(FID)
12	*	12.000	1	INPUT(5)
13	*	13.000		CBUNT=0.0
14	*	14.000		WREC0V=10000.
15	*	15.000		SRMISS=10000.
16	*	16.000	C	
17	*	17.000	C	BASIC SRM WEIGHT
18	*	18.000	C	
19	*	19.000	C	GEOMETRY EQUATIONS
20	*	20.000		VPC=(PR0PB/RH0P)*(1.292674*DIA*DIA*DIA*(MIA/MAAX))
21	*	21.000		TCYL=(ME0P*DIA*FS/(2.0*FTU))*INT
22	*	22.000		ACS=(3.14159/4.0)*(DIA*TCYL)*(DIA*TCYL)
23	*	23.000		LTH=VPC/(ACS*AP)
24	*	24.000		VCASE=(3.14159/6.0)*DIA*DIA*DIA*(MIA/MAAX)
25	*	25.000		1*(3.14159/4.0)*DIA*DIA*(VPC/(ACS*1.3*AT))
26	*	26.000		PLE=PR0PB/(RH0P*VCASE)
27	*	27.000		PXB1=PR0PB/1.005
28	*	28.000	C	CASE WEIGHT
29	*	29.000		IF (PR0PB.LT.3000.0R,PR0PB.GT.2000000.0) CBUNT=1.0
30	*	30.000		IF (ME0P.LT.500.0R,ME0P.GT.1500.0) CBUNT=1.0
31	*	31.000		IF ((LTH/DIA).LT.25.0R,(LTH/DIA).GT.5.0) CBUNT=1.0
32	*	32.000		IF ((MIA/MAAX).LT.6.0R,(MIA/MAAX).GT.1.0) CBUNT=1.0
33	*	33.000		IF (CBUNT.EQ.1.0) WRITE(10R,700)
34	*	34.000		CASE1=RH0M*(PR0PB/(RH0P*NP))*95
35	*	35.000		CASE2=ME0P**7*FS**7/FTU**9
36	*	36.000		CASE3=(LTH/DIA)**((1.163*MIA/MAAX)-.114)
37	*	37.000		CASE4=(MIA/MAAX)**.315
38	*	38.000		WCASE=11.16*(CASE1+CASE2*(CASE3/CASE4))*1.013
39	*	39.000	C	CASE JBUNT WEIGHT
40	*	40.000		WJBUNT=7.7*DIA*DIA*(ME0P*FS*NJ/FTU)
41	*	41.000	C	NOZZLE WEIGHT
42	*	42.000		IF (PR0PB.LT.500.0R,PR0PB.GT.2000000.0) CBUNT=2.0
43	*	43.000		IF (BBT.LT.30.0R,BBT.GT.140.0) CBUNT=2.0
44	*	44.000		IF (PC.LT.300.0R,PC.GT.1000.0) CBUNT=2.0
45	*	45.000		IF (NER.LT.5.0R,NER.GT.75.0) CBUNT=2.0
46	*	46.000		IF (NDHA.LT.15.0R,NDHA.GT.30.0) CBUNT=2.0
47	*	47.000		IF (CBUNT.EQ.2.0) WRITE(10R,800)
48	*	48.000	C	FIXED NOZZLE
49	*	49.000		NBZZ1=BBT**6*TH0SL**1.2*NER**7
50	*	50.000		NBZZ2=CF**1.2*PC**8*(TAN(NDHA/57.29578))**4
51	*	51.000		IF (WNRZ.GT.0.0) GO TO 10
52	*	52.000		WNBZZ=.003505*(NBZZ1/NBZZ2)**.916
53	*	53.000		GO TO 20
54	*	54.000	C	GIMBALLED NOZZLE
55	*	55.000	10	KGN=2.11/NER**1.16

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TABLE 5.4-4  
PROGRAM LISTING (Continued)

```

56 * 56.000      WN0ZZ=.003505*KGN*(N0ZZ1/N0ZZ2)**.916
57 * 57.000 C    THRUST TERMINATION WEIGHT
58 * 58.000 20   WTTT=.03512*(TH0SL/(CF*PC))**.45
59 * 59.000 C    INSULATION WEIGHT
60 * 60.000      IF (PR0PB.LT.2000..0R.PR0PB.GT.3000000.) CBUNT=3.0
61 * 61.000      IF (BBT.LT.40..0R.BBT.GT.140.) CBUNT=3.0
62 * 62.000      IF (PC.LT.300.0R.PC.GT.1200.) CBUNT=3.0
63 * 63.000      IF (TC.LT.5000..0R.TC.GT.6500.) CBUNT=3.0
64 * 64.000      IF ((LTH/DIA).LT..25.0R.(LTH/DIA).GT.8.) CBUNT=3.0
65 * 65.000      IF (CBUNT.EG.3.0) WRITE (ICR,300)
66 * 66.000 C    CASE
67 * 67.000      INSC1=(PR0PB/(RH0P*NP))**.80
68 * 68.000      INSC2=BBT**.5*PC**.117*(TC/1000.)*(TC/1000.)
69 * 69.000      INSC3=(LTH/DIA)**.1*TCES**.2
70 * 70.000      WINS0=.000602*(INSC1*(INSC2/INSC3))**.86
71 * 71.000 C    JBINT
72 * 72.000      DP=((AP/AT)*(4.0*TH0SL/(3.14159*CF*PC))**.6
73 * 73.000      WUJ=.00054*(DIA/DP)*DIA*BBT
74 * 74.000      WII=.000178*(DIA-DP)*((2.*DIA+DP)*BBT+80.*DIA)
75 * 75.000      IF (WFI.GT.0.0) GO TO 33
76 * 76.000      WINSJ=2.C*WUJ*WII
77 * 77.000      GO TO 35
78 * 78.000 33   WINSJ=(WUJ+WII)*WII
79 * 79.000 35   WINST=WINS0+WINSJ
80 * 80.000 C    IGNITER WEIGHT
81 * 81.000      WIGN=.33658*DIA**.45
82 * 82.000      EXPINS=.005*PR0PB
83 * 83.000      BASSRM=CASE+WJBINT+WN0ZZ+WTTT+WINSJ+WIGN+BSRMC
84 * 84.000      UNCERT=PUNC1*(WRECBV+SRMISS)+BUNC2*(BASSRM)
85 * 85.000      BB0WT=BASSRM+SRMISS+WRECBV+UNCERT+EXPINS
86 * 86.000      BL0WT=BB0WT+PR0PB*FXPINS
87 * 87.000 30   TB0WT=BB0WT
88 * 88.000      TBL0WT=BL0WT
89 * 89.000 C
90 * 90.000 C    RECOVERY SYSTEM WEIGHT
91 * 91.000 C
92 * 92.000 C    PARACHUTE WEIGHT
93 * 93.000      WPAR=175.0+498.0*(BB0WT/(VRI*VRI))
94 * 94.000 C    PARACHUTE INST WEIGHT
95 * 95.000      WPI=.6916*WPAR
96 * 96.000 C    RETRO ROCKET WEIGHT
97 * 97.000      WRR=.0819*BB0WT*(VRI-VSD)/RRISP
98 * 98.000 C    PROPELLANT WEIGHT
99 * 99.000      WRP=.675*WRR
100 * 100.000 C  WATER RECOVERY HDW WEIGHT
101 * 101.000      WAR=380.
102 * 102.000 C
103 * 103.000 C    SRM BODY ADAPTER WEIGHT
104 * 104.000 C
105 * 105.000 C    FORWARD SKIRT
106 * 106.000      WFS=13.65*DIA
107 * 107.000 C    AFT SKIRT/LAUNCH STRUCTURE WEIGHT
108 * 108.000      ASLS1=(BGL0W+(2.0*BL0WT))/4.0
109 * 109.000      ASLS2=.65*TH0SL*C08(A08E/57.292578)*(LF+(DIA/2.))
110 * 110.000      WASLS=.00464*(ASLS1+(ASLS2/DIA))
111 * 111.000 C    ATTACH SEP/STRUCTURE WEIGHT
112 * 112.000      WAS=952.C*TH0SL/BB0WT
113 * 113.000 C    NOSE FAIRING
114 * 114.000      WNF=.0617*DIA*DIA
115 * 115.000 C    TUNNEL WEIGHT
116 * 116.000      WTA=.114*LTH

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PROGRAM LISTING (Continued)

```

117 • 117.000 C   AVIONICS WEIGHT
118 • 118.000   WAV=182.0
119 • 119.000 C   TPS WEIGHT
120 • 120.000   WNCTPS=.018*DIA*DIA
121 • 121.000   SRMISS=VFS+WASLS+WAS+WNF+WTN+WAV+WNCTPS+SRMIC
122 • 122.000   WRECBV=WPJ+WRR+WRP+WWR+SRMRC
123 • 123.000   UNCERT=BUNC1*(WRECBV+SRMISS)+BUNC2*(BASSRM)
124 • 124.000   BBWWT=BASSRM+SRMISS+WRECBV+UNCERT+EXPINS
125 • 125.000   BLWWT=BBWWT+PRBPB+EXPINS
126 • 126.000   BGLBW=BGLWT
127 • 127.000   LAMB=PRBPB/BGLBW
128 • 128.000   IF(ABS(TBBWWT-BBWWT).LE.10.) GO TO 40
129 • 129.000   GO TO 30
130 • 130.000 40   WRITE(108,1000)
131 • 131.000   WRITE(108,1010) BASSRM
132 • 132.000   WRITE(108,1020) WCASE,WJBINT,WNOZZ,WTER,WINST,WIGN,BSRMC
133 • 133.000   WRITE(108,1030) WRECBV
134 • 134.000   WRITE(108,1040) WPAR,WPI,WRR,WRP,WWR,SRMRC
135 • 135.000   WRITE(108,1050) SRMISS
136 • 136.000   WRITE(108,1060) WFS,WASLS,WAS,WNF,WTN,WAV,WNCTPS,SRMIC
137 • 137.000   WRITE(108,1070) UNCERT,EXPINS
138 • 138.000   WRITE(108,1080) BBWWT,PRBPB,LAMB,BGLBW
139 • 139.000 700   FORMAT(//14X,1***WARNING L88K AT CASE AND J8INT PARAMETERS***1)
140 • 140.000 800   FORMAT(//17X,1***WARNING L89K AT NBZZLE PARAMETERS***1)
141 • 141.000 900   FORMAT(//15X,1***WARNING L89K AT INSULATION PARAMETERS***1)
142 • 142.000 1000  FORMAT(//22X,1WEIGHT SUMMARY (PER SRM) = LB,1)
143 • 143.000 1010  FORMAT(//22X,1BASIC SRM WEIGHT,4X,1(1,F10.0,1)1)
144 • 144.000 1020  FORMAT(//22X,1CASE WEIGHT,10X,F10.0,1,22X,
145 • 145.000   1'JBINT WEIGHT,9X,F10.0,1,22X,1NBZZLE WEIGHT,8X,
146 • 146.000   2F10.0,1,22X,1THRUST TER WEIGHT,4X,F10.0,1,22X,
147 • 147.000   3'INSULATION WEIGHT,4X,F10.0,1,22X,1IGNITER WEIGHT,7X
148 • 148.000   4,F10.0,1,22X,1BASIC SRM WT. CONST,1,1X,F10.0)
149 • 149.000 1030  FORMAT(//22X,1SRM RECOVERY WEIGHT,1X,1(1,F10.0,1)1)
150 • 150.000 1040  FORMAT(//22X,1PARACHUTE WEIGHT,5X,F10.0,1,22X,
151 • 151.000   1'PARACHUTE INST,1,4X,F10.0,1,22X,1RETR8 ROCKET,9X,
152 • 152.000   2F10.0,1,22X,1PROPELLANT WEIGHT,4X,F10.0,1,22X,
153 • 153.000   3'WATER REC. HWO,1,4X,F10.0,1,22X,1SRM REC. WT. CONST,1
154 • 154.000   2X,F10.0)
155 • 155.000 1050  FORMAT(//22X,1SRM INTERSTAGE ST,1,2X,1(1,F10.0,1)1)
156 • 156.000 1060  FORMAT(//22X,1FORWARD SKIRT,1,4X,F10.0,1,22X,
157 • 157.000   1'AFT SKIRT ST,1,6X,F10.0,1,22X,1ATTACH/SEP STRUCT,1
158 • 158.000   2,4X,F10.0,1,22X,1NOSE FAIRING,9X,F10.0,1,22X,
159 • 159.000   3'TUNNEL WEIGHT,8X,F10.0,1,22X,1AVIONICS WEIGHT,6X,
160 • 160.000   4F10.0,1,22X,1TPS WEIGHT,11X,F10.0,1,22X,1SRM INTERS. CONST,1
161 • 161.000   5,4X,F10.0)
162 • 162.000 1070  FORMAT(//22X,1UNCERTAINTY WT,1,5X,1(1,F10.0,1)1,1,22X,
163 • 163.000   1'EXPENDABLES,9X,1(1,F10.0,1)1)
164 • 164.000 1080  FORMAT(//22X,1SRM BURNOUT WEIGHT,2X,1(1,F10.0,1)1,
165 • 165.000   1,22X,1SRM PR9P. WEIGHT,4X,1(1,F10.0,1)1,22X,1LAMBDA,1
166 • 166.000   2,2X,F5.3,1,22X,1SRM GROSS WEIGHT,3X,1(1,F10.0,1)1)
167 • 167.000   GO TO 1
168 • 168.000 9999  CALL LLOSF5
169 • 169.000   STOP
170 • 170.000   END

```



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6. REFERENCES

- A. "Optimized Cost/Performance Design Methodology", McDonnell Douglas Corporation Report No. E005, dated 1 September 1969. Submitted under Contract NAS2-5022 to NASA OART.
- B. Structures Handbook, Report 339, McDonnell Aircraft Company, Revised 1 December 1971.
- C. "Formulas for Stress and Strain", Raymond J. Roark, McGraw-Hill Book Company, 1954.
- D. "Weight-Strength Analysis of Aircraft Structures", R. F. Shanley, 1960.
- E. Royal Aeronautical Society, Transonic Data Memorandum 6403, "Method for the Rapid Estimation of Theoretical Spanwise Loading due to a Change in Incidences", Issued March 1964.
- F. Society of Aeronautical Weight Engineers Technical Report 73, "Estimation of Wing Bending Material by Multiple Station Analysis," A. L. Kirkpatrick, May 1952.
- G. "Optimization of Multirib and Multiweb Wing Box Structures Under Shear and Moment Loads," A paper by Emero, Donald H. and Spunt, Leonard, North American Aviation, Inc. Los Angeles Division, presented at the AIAA Conference, 1965.
- H. "Optimum Design of Multiweb Beams in Bending", McDonnell Aircraft Corporation. Report No. 3525, Revised 13 March 1960.
- I. "Structural Analysis Bulletins", McDonnell Aircraft Corporation Report No. 338, revised 2 January 1969.
- J. "Hypersonic Aerospace-Vehicle Structures Program - Volume II - Generalized Mass Properties Analysis," AFFDL-TR-68-129, Volume II, Parts I and II, January 1969.
- K. "Space Shuttle Program Information Note-Loads", PIN-S-1E-LOADS-1 (122.1) McDonnell Douglas Astronautics Company, 7 June 1972.
- L. "Space Shuttle Mass Properties Status," North American Rockwell Report SD72-SH-0120-3, 2 December 1972.
- M. "Parametric Weight Scaling Equations for Solid Propellant Launch Vehicles," Aerospace Report No. TR-669 (6560)-2, April 1966.
- N. "Development of a Weight/Sizing Synthesis Computer Program - Program Plan," McDonnell Douglas Corporation Report No. E0645, 28 June 1972.
- O. "Analysis and Design of Flight Vehicle Structures", E. F. Bruhn, Tri-State Offset Company, 1965.

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- P. "Metallic Materials and Elements for Aerospace Vehicle Structures", MIL-HDBK-5B, 1971.
- Q. "Weight Estimation Handbook", McDonnell Aircraft Corporation Report No. 747, (Not Released).
- R. "Computer Aided Stabilator Design Including Aeroelastic Constraints", W. E. Tripplet and K. D. Ising, McDonnell Aircraft Corporation. Presented at the 11th Structural, Structural Dynamics, and Materials Conference of AIAA and ASME, Denver, Colorado, 22-24 April 1970 (MDC 70-006).
- S. "Development of a Weight/Sizing Design Synthesis Computer Program - Midterm Report", McDonnell Douglas Report No. E0706, Contract NAS9-12989, 8 November 1972.

APPENDIX A  
SINGLE FACE CORRUGATION SHELL WEIGHT MODEL

In advanced design studies, it is not practical to analyze each structural item in sufficient depth to determine its associated weight. Therefore, weight estimation models, correlated where possible to hardware, are required. These models are not intended to yield optimized structural designs. They must, however, provide data adequate to define reasonable weights and their sensitivities to the design and performance criteria applicable to each advanced design study.

Spacecraft have body structural shells which vary from cylindrical or conical cross sections to flat-sided, noncircular cross sections. It is necessary to consider a structural concept that can accommodate all of these shapes and still provide adequate strength and stiffness during all mission phases. Two basic requirements of the inner body shell structure are to provide load paths for carrying aerodynamic and inertia-induced loads (i.e., body bending moments, axial loads, and shear loads), and to provide a pressure shell for carrying internal pressures. When this latter condition occurs simultaneously with aerodynamic and inertia loads, the structural shell is analyzed using beam-column analysis.

The analytical equations are developed for a single skin, stiffened longitudinally with open-face trapezoidal corrugations as illustrated in Figure A-1.

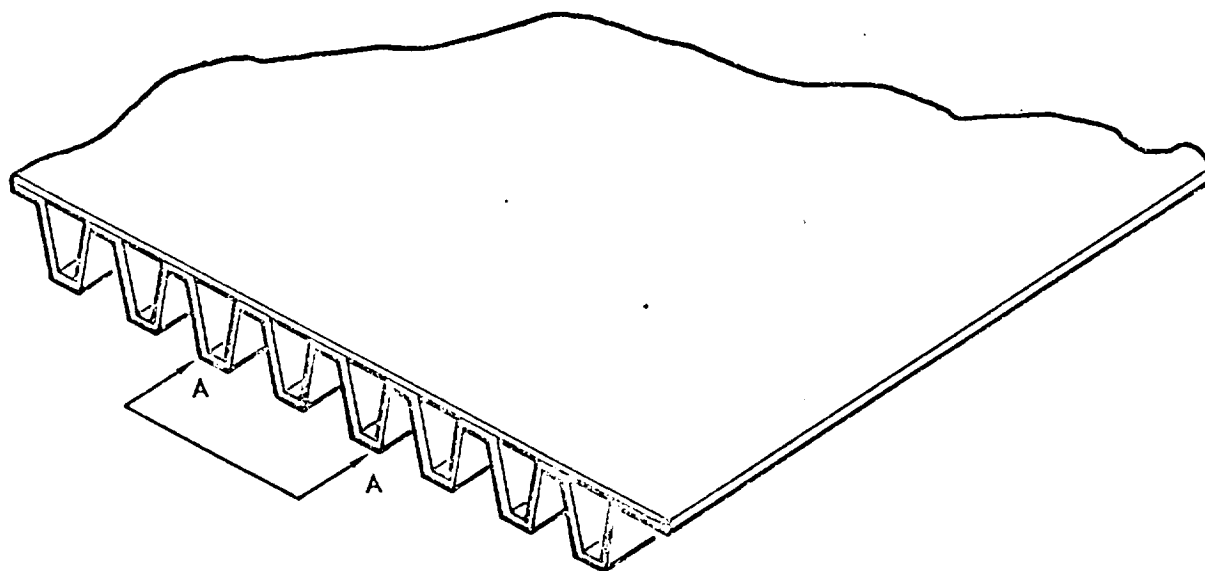
Single-skin, open-face corrugations are analyzed as though each pitch of skin corrugation acts as an individual beam-column. Beam-column length is equal to the interval between frames. Boundary conditions consider the primary shell skin to exhibit negligible hoop tension or compression capability; therefore, each pitch of skin corrugation beams the entire lateral pressure loads to structural frames. Extent of conservatism exhibited by assuming negligible hoop capabilities is highly dependent upon shell deviation from a cylindrical cross section. Cylindrical shells provide excellent load paths for carrying hoop loads.

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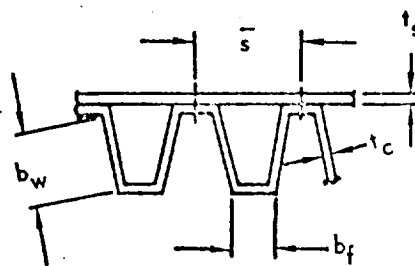
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## SYMBOLS USED IN EQUATIONS

$F_{tu}$	ultimate tensile strength, $\text{lb/in}^2$
$F_{cy}$	compressive yield strength, $\text{lb/in}^2$
$E$	Young's modulus of elasticity, $\text{lb/in}^2$
$F_{cc}$	crippling stress, $\text{lb/in}^2$
$F_c$	allowable column stress, $\text{lb/in}^2$
$F_{rb}$	reference bending stress employed in plastic bending analysis, $\text{lb/in}^2$
$P$	applied, ultimate axial load, lb
$P_c$	allowable column load per Johnson's equation, lb
$P_{cr}$	critical column load per Euler's equation, lb
$P_{all}$	axial load at failure, lb
$q$	applied, ultimate uniform radial loading, $\text{lb/in}$
$q$	applied, ultimate pressure, $\text{lb/in}^2$
$M$	applied, ultimate bending moment, in-lb
$M_o$	bending moment due to lateral load and corresponding to $y_o$ , in-lb
$M_{all}$	allowable bending moment in plastic bending, in-lb
$y$	maximum final or total deflection, in
$y_o$	maximum deflection due to lateral and/or moment plus initial eccentricity - in
$\alpha$	ratio of $P/P_{cr}$ or $P_{all}/P_{cr}$ , scalar
$\frac{1}{1-\alpha}$	deflection magnification factor, scalar
$A$	cross-sectional area of beam or column, $\text{in}^2$
$L$	beam-column length, spacing between frames, in
$L'$	effective beam-column length, $L' = L/\sqrt{C_f}$ , in
$t$	thickness, in
$b$	element width used in crippling equations, in
$s$	corrugation pitch, in
$I$	area moment of inertia, $\text{in}^4$
$\rho$	material density, $\text{lb/in}^3$
$Q$	static moment of area about neutral axis for plastic bending, $\text{in}^3$
$Z$	section modulus, $\text{in}^3$
$\bar{W}$	unit weight, $\text{lb/ft}^2$
$k$	radius of gyration, in
$C_f$	fixity coefficient, scalar



$$\begin{aligned} t_s &= 0.488 \bar{r} \\ s &= 20 t_s \\ t_c &= 0.5 t_s \\ b_f &= 6.0 t_s \\ b_w &= 15.0 t_s \end{aligned}$$



View A-A

FIGURE A-1  
SINGLE-SKIN, TRAPEZODIAL CORRUGATION GEOMETRY  
(Sizing Model)

The following work develops the shell sizing model which is taken directly from Reference b.

Beam Columns - A beam-column is a compression member which is also subjected to bending loads. Bending may be caused by eccentric application of the member, lateral loadings, or a combination of these.

The final deflection at the center is:

$$y = y_o \left( \frac{1}{1-\alpha} \right)$$

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The moment on the column can then be expressed by the following equation:

$$M = P_y + M_o$$

The margin of safety of a beam-column can be calculated using the following interaction formula:

$$R_b + R_c = 1,$$

where

$$R_b = \frac{P_{all} \left( \frac{y_o}{1-\alpha} \right) + M_o}{M_{all}}$$

and

$$R_c = \frac{P_{all}}{F_{cc} A}$$

Substituting the ratios  $R_b$  and  $R_c$  into the interaction formula yields the following equation:

$$\left( \frac{P_{cr}}{F_{cc} A} \right) \left( \frac{P_{all}}{P_{cr}} \right)^2 - \left( \frac{P_{cr}}{F_{cc} A} + \frac{P_{cr} y_o}{M_{all}} - \frac{M_o}{M_{all}} + 1 \right) \left( \frac{P_{all}}{P_{cr}} \right) - \frac{M_o}{M_{all}} + 1 = 0$$

This is a quadratic equation with  $P_{all}/P_{cr}$  as the unknown. It can be solved by the usual quadratic formula:

$$\frac{P_{all}}{P_{cr}} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

where

$$a = \frac{P_{cr}}{F_{cc} A}$$

$$b = - \left( \frac{P_{cr}}{F_{cc} A} + \frac{P_{cr} y_o}{M_{all}} - \frac{M_o}{M_{all}} + 1 \right)$$

$$c = - \frac{M_o}{M_{all}} + 1$$

The negative sign before the radical gives the proper answer when substituted into the following expression:

$$P_{all} = P_{cr} \left( \frac{P_{all}}{P_{cr}} \right)$$

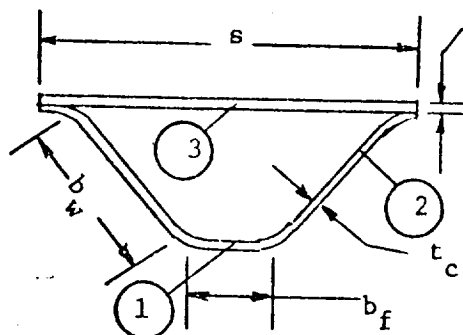


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Before proceeding, it is necessary to solve for the quadratic equation coefficients,  $a$ ,  $b$ , and  $c$ , in terms of the single-skin, open-face corrugation geometry. This is accomplished in five basic steps:

(1) determination of allowable crippling stress ( $F_{cc}$ ) - To determine allowable crippling stress, the following geometric relationships are used:



$$\begin{aligned} t_s &= 0.05s & A &= 0.1025s^2 \\ t_c &= 0.025s & I &= 0.0074s^4 \\ b_f &= 0.30s \\ b_w &= 0.75s \end{aligned}$$

From Reference b, the crippling stress for a no-edge, free element may be found from the equation:

$$F_{cc} = 1.41 \frac{F_{cy}}{E}^{.595} \frac{E}{\left(\frac{b}{t}\right)^{0.81}}$$

For a given element, the maximum value allowed for  $F_{cc}$  is  $F_{tu}$ . In any equation used for determining the composite crippling stress of a skin corrugation, it is necessary to account for three geometrically different elements as follows:

Element 1, where  $\frac{b_f}{t_c} = \frac{0.30s}{0.025s} = 12$

Element 2, where  $\frac{b_w}{t_c} = \frac{0.75s}{0.025s} = 30$

and

Element 3, where  $\frac{s}{t_s} = \frac{1.s}{0.05s} = 20.$

The following combinations of conditions are possible stress levels for the skin-corrugation elements:

- (a) no elements working at  $F_{tu}$
- (b) one element working at  $F_{tu}$
- (c) two elements working at  $F_{tu}$
- (d) all three elements working at  $F_{tu}$

For each possible combination, a composite  $F_{cc}$  of skin corrugation is obtained from the following equations shown in Table A-1.

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TABLE A-1  
EQUATIONS

$$\text{Define } Z = \frac{E}{F_{tu}} \frac{F_{cy}}{E} \quad 0.595$$

Lower Limit Z	Upper Limit Z	
0	5.3	$\frac{F_{cc}}{F_{tu}} = 0.1215 Z$
5.3	8.02	$\frac{F_{cc}}{F_{tu}} = 0.094 Z + 0.146$
8.02	11.11	$\frac{F_{cc}}{F_{tu}} = 0.0328 Z + 0.634$
11.11	$\infty$	$\frac{F_{cc}}{F_{tu}} = 1.$

(2) determination of allowable buckling load ( $P_c$ ) - The allowable buckling load is calculated from Johnson's Parabola for short columns:

$$P_c = F_{cc} A - \frac{F_{cc}^2 (L'/k)^2}{4\pi^2 E} A$$

For the skin-corrugation structure with a full fixity as the assumed boundary condition, the Johnson's equation becomes:

$$P_c = 0.1025 L^2 \left[ \frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^2}{2.8546 C_f E} \right]$$

Calculating the column stress from Johnson's equation,

$$F_c = \frac{P_c}{A}$$

It must be verified that  $F_c$  is equal to or greater than one-half of  $F_{cc}$ . If this is not the case, then basic Euler column equation replaces Johnson's equation, or:

$$P_c = \pi^2 \frac{EI}{(L')^2} \quad \text{and} \quad F_c = \frac{P_c}{A}$$

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(3) determination of initial deflection ( $y_o$ ) and initial moment ( $M_o$ ) - These values are obtained from "Formulas for Stress and Strains," by R. J. Roark, 4th ed., dated 1965, for a beam carrying a uniform lateral load. The equations, after substituting appropriate geometries, are:

$$y_o = \frac{k_1}{2.84} \frac{qL^4}{Es^3}$$

and

$$M_o = \frac{1}{k_2} C_f qSL^2$$

The values of  $k_1$  and  $k_2$  are given in Table A-2.

TABLE A-2  
FIXITY CONSTANTS

fixity condition	$C_f$	$k_1$	$k_2$
both ends fixed	4.00	1.00	12.00
both ends pinned	1.00	5.00	8.00
one fixed, one pinned	2.04	2.30	9.95
one fixed, one free	0.25	47.97	4.00

(4) determination of allowable bending moment ( $M_{all}$ ) - In determining the allowable bending moment, the basic plastic bending equation found in Reference b is employed:

$$M_{all} = (Q_1 + Q_2) F_{rb}$$

Substituting the geometric relationship for the skin corrugation into this expression, the following expression for  $M_{all}$  is obtained.

$$M_{all} = 0.0193s^3 F_{tu}$$

(5) quadratic equation coefficients - The coefficients a, b, and c are expressed as follows:

$$a = \frac{P_c}{F_{cc} A} = \frac{\left[ \frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^2}{2.8546 C_f E} \right]}{\left[ \frac{F_{cc}}{(L/s)^2} \right]}$$

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$$b = - [(a+c) + \frac{k_1 k_2 C_f}{284} \frac{L}{E} \left(\frac{P_c}{L}\right)^4 \left(\frac{L}{s}\right)^4 \frac{1}{L} \left(\frac{M_o}{M_{all}}\right)], \text{ and}$$

$$c = 1 - \frac{1}{0.0193 k_2 C_f} \left(\frac{L}{s}\right)^2 \left(\frac{q}{F_{tu}}\right).$$

where

$$\text{if } F_c \geq 1/2 F_{cc}, P_c = .1025 L^2 \left[ \frac{F_{cc}}{(L/s)^2} - \frac{F_{cc}^2}{2.8546 C_f E} \right] \text{ (Johnson's equation)}$$

$$\text{If } F_c < 1/2 F_{cc}, \text{ then } P_c = \pi^2 \frac{EI}{(L')^2} \text{ (Euler's equation)}$$

The subroutine utilizes an iterative process where values of the skin thickness ( $t_s$ ) are varied until  $P_{all}$  approaches  $P$ , or the margin of safety approaches zero. As shown on Figure 1, the value calculated for  $t_s$  must satisfy the requirement:

$$\frac{t_s}{2} = t_c \geq t_{\text{minimum}}$$

The value  $t_{\text{minimum}}$  represents a minimum sheet thickness, based upon manufacturing and/or handling limitations used in the aerospace industry.

Using the relation between skin thickness ( $t_s$ ) and equivalent thickness ( $\bar{t}$ ) shown on Figure A-1, the shell unit weight is determined by:

$$\bar{W} = 144 \rho \bar{t}$$

Circular Shells - As previously discussed, cylindrical and conical shells are capable of carrying hoop loads. However, the present equations do not account for this capability. Therefore, conical shells, which are employed on ballistic vehicles, cargo propulsion modules, and launch vehicle adapters, are conservatively sized by the techniques for noncircular shells.

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A.1 - General Instructions - This is a program for finding the unit weight of a single-face corrugation shell for a given running load, operating temperature, and material. A linear expression giving unit weight in terms of running load is produced as well. Three outputs are given which can be used as inputs to the Aerosurface Calculation Program.

REQUIRED INPUT

The input form used is the "namelist" type which eliminates any fixed format problems. The namelist variables used are given below.

<u>Name</u>	<u>Variable</u>	<u>Units</u>
E	Young's Modulus of elasticity at operating temp.	lb/in <sup>2</sup>
FTU	Ultimate tensile strength at operating temp.	lb/in <sup>2</sup>
FCY	Compressive yield strength at operating temp.	lb/in <sup>2</sup>
MATL(I), I=1,3	Material Name	--
RHO	Material Density	lb/in <sup>3</sup>
RS	Rib Spacing	in
TEMP	Operating temperature	°F
Q	Running Load	lb/in
FIX	Indicator of fixity condition	--
	1 - both ends fixed	
	2 - both ends pinned	
	3 - one end fixed, one end pinned	
	4 - one end fixed, one end free	
LIM	Variable limiting number of points per run (for LIM = 50, Q RUN <sub>MAX</sub> = 32000 lb/in.)	

Table A-3 is a typical input file for various materials, temperatures, and pressures. Tables A-4 through A-10 are the resulting outputs for these data, and Table A-11 is a Fortran listing of the Shell Program.

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TABLE A-3  
SAMPLE INPUT FILE

1.000 ALUM 2024-T861  
2.000 E=10.5E+06,FTU=71000.,FCY=63000.,RHO=.1,RS=20.,TEMP=70.  
3.000 Q=1.4,FIX=3,LIM=43\*  
4.000 ALUM 2014-T651  
5.000 E=10.7E+06,FTU=66000.,FCY=59000.,RHO=.101\*  
6.000 ALUM 2219-T87  
7.000 E=10.5E+06,FTU=64000.,FCY=53000.,RHO=.102\*  
8.000 ALUM 7075-T651  
9.000 E=10.3E+06,FTU=78000.,FCY=69000.,RHO=.101\*  
10.000 ALUM 7079-T651  
11.000 E=10.3E+06,FTU=76000.,FCY=68000.,RHO=.099\*  
12.000 TITANIUM 6AL-4V  
13.000 E=16.0E+06,FTU=160000.,FCY=154000.,RHO=.160\*  
14.000 TITANIUM 6AL-4V  
15.000 E=13.1E+06,FTU=118000.,FCY=98000.,RHO=.160  
16.000 TEMP=600.\*

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TABLE A-4  
RESULTING OUTPUTS

ALUM 2024-T861                      TEMP= 70. F    Q= 1.40 PSI  
E= .105E 03 PSI    FTU= 71000. PSI    FCY= 63000. PSI  
RHO= .100 LB/IN3    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04            (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.51	10	7500.	2.34	5
200.	.61	7	8000.	2.44	5
300.	.68	5	8500.	2.55	5
400.	.74	3	9000.	2.66	5
500.	.80	5	9500.	2.77	5
600.	.84	5	10000.	2.89	5
700.	.88	5	11000.	3.11	5
800.	.92	6	12000.	3.34	5
900.	.95	6	13000.	3.57	5
1000.	.98	6	14000.	3.80	5
1500.	1.12	6	15000.	4.04	5
2000.	1.23	5	16000.	4.28	5
2500.	1.32	5	17000.	4.51	5
3000.	1.42	5	18000.	4.75	5
3500.	1.51	5	19000.	4.99	5
4000.	1.62	4	20000.	5.23	5
4500.	1.71	4	21000.	5.48	5
5000.	1.81	5	22000.	5.72	5
5500.	1.91	5	23000.	5.96	5
6000.	2.02	5	24000.	6.20	5
6500.	2.12	5	25000.	6.45	5
7000.	2.23	5			

SLOPE= .000227 PSF/LB/IN            CB= .68 PSF  
FA= 63444. PSI            TAU= 22010. PSI  
WBAR= .000227 \* QRUN + .68

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TABLE A-5  
RESULTING OUTPUTS

ALUM 2014-T651      TEMP= 70. F    Q= 1.40 PSI  
E= .107E 03 PSI    FTU= 66000. PSI    FCY= 59000. PSI  
RHO= .101 LB/IN3    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04    (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.52	10	7500.	2.41	5
200.	.62	7	8000.	2.53	5
300.	.69	5	8500.	2.64	5
400.	.75	3	9000.	2.76	5
500.	.80	5	9500.	2.88	5
600.	.85	5	10000.	3.00	5
700.	.89	5	11000.	3.23	5
800.	.93	5	12000.	3.48	5
900.	.96	6	13000.	3.72	5
1000.	.99	6	14000.	3.97	5
1500.	1.13	5	15000.	4.21	5
2000.	1.24	4	16000.	4.46	5
2500.	1.34	5	17000.	4.71	5
3000.	1.44	5	18000.	4.97	5
3500.	1.55	4	19000.	5.22	5
4000.	1.65	4	20000.	5.47	5
4500.	1.75	5	21000.	5.73	5
5000.	1.86	5	22000.	5.98	5
5500.	1.97	5	23000.	6.24	5
6000.	2.08	5	24000.	6.50	5
6500.	2.19	5	25000.	6.75	5
7000.	2.30	5			

SLOPE= .000240 PSF/LB/IN    CB= .66 PSF

FA= 60672. PSI    TAU= 20460. PSI

WBAR= .000240 \* QRUN + .66



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TABLE A-6  
RESULTING OUTPUTS

ALUM 2219-T87                      TEMP= 70. F     $\sigma = 1.40$  PSI  
E= .105E 08 PSI    FTU= 64000. PSI    FCY= 53000. PSI  
RHO= .102 LB/IN<sup>3</sup>    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04            (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.52	10	7500.	2.54	5
200.	.63	7	8000.	2.67	5
300.	.71	4	8500.	2.79	5
400.	.77	4	9000.	2.92	5
500.	.82	5	9500.	3.05	5
600.	.86	5	10000.	3.18	5
700.	.91	5	11000.	3.44	5
800.	.95	5	12000.	3.70	5
900.	.98	6	13000.	3.96	5
1000.	1.01	6	14000.	4.23	5
1500.	1.15	5	15000.	4.50	5
2000.	1.26	5	16000.	4.77	5
2500.	1.37	5	17000.	5.04	5
3000.	1.48	5	18000.	5.32	5
3500.	1.60	4	19000.	5.59	5
4000.	1.71	3	20000.	5.86	5
4500.	1.82	5	21000.	6.14	5
5000.	1.94	5	22000.	6.42	5
5500.	2.06	5	23000.	6.69	5
6000.	2.18	5	24000.	6.97	5
6500.	2.30	5	25000.	7.24	4
7000.	2.42	5			

SLOPE= .000260 PSF/LB/IN            CB= .64 PSF  
FA= 56462. PSI            TAU= 19840. PSI  
WBAR= .000260 \* QRUN + .64

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TABLE A-7  
RESULTING OUTPUTS

ALUM 7075-T651      TEMP= 70. F    O= 1.40 PSI  
E= .103E 08 PSI    FTU= 78000. PSI    FCY= 69000. PSI  
RHO= .101 LB/IN3    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04    (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.51	10	7500.	2.29	5
200.	.61	7	8000.	2.39	5
300.	.69	5	8500.	2.49	5
400.	.75	3	9000.	2.60	5
500.	.80	5	9500.	2.70	5
600.	.85	5	10000.	2.81	5
700.	.89	5	11000.	3.02	5
800.	.93	6	12000.	3.24	5
900.	.96	6	13000.	3.46	5
1000.	1.00	6	14000.	3.68	5
1500.	1.13	6	15000.	3.90	5
2000.	1.24	5	16000.	4.12	5
2500.	1.34	6	17000.	4.35	5
3000.	1.43	5	18000.	4.58	5
3500.	1.52	5	19000.	4.80	5
4000.	1.61	5	20000.	5.03	5
4500.	1.71	4	21000.	5.26	5
5000.	1.80	4	22000.	5.49	5
5500.	1.89	5	23000.	5.72	5
6000.	1.99	5	24000.	5.96	5
6500.	2.09	5	25000.	6.19	5
7000.	2.19	5			

SLOPE= .000215 PSF/LB/IN    CB= .72 PSF  
FA= 67641. PSI    TAU= 24180. PSI  
WBAR= .000215 \* QRUN + .72

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TABLE A-8  
RESULTING OUTPUTS

ALUM 7079-T651      TEMP= 70. F    Q= 1.40 PSI  
E= .103E 08 PSI    FTU= 76000. PSI    FCY= 68000. PSI  
RHO= .099 LB/IN3    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04    (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.50	10	7500.	2.26	5
200.	.60	7	8000.	2.36	5
300.	.68	5	8500.	2.46	5
400.	.74	3	9000.	2.57	5
500.	.79	5	9500.	2.67	5
600.	.83	5	10000.	2.78	5
700.	.88	5	11000.	2.99	5
800.	.91	6	12000.	3.20	5
900.	.95	6	13000.	3.42	5
1000.	.98	6	14000.	3.64	5
1500.	1.11	6	15000.	3.86	5
2000.	1.22	5	16000.	4.08	5
2500.	1.31	6	17000.	4.31	5
3000.	1.40	5	18000.	4.53	5
3500.	1.49	5	19000.	4.76	5
4000.	1.58	5	20000.	4.99	5
4500.	1.68	4	21000.	5.21	5
5000.	1.77	4	22000.	5.44	5
5500.	1.86	5	23000.	5.67	5
6000.	1.96	5	24000.	5.90	5
6500.	2.06	5	25000.	6.13	5
7000.	2.16	5			

SLOPE= .000214 PSF/LB/IN    CB= .70 PSF  
FA= 66721. PSI    TAU= 23560. PSI  
WBAR= .000214 \* QRUN + .70

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TABLE A-9  
RESULTING OUTPUTS

TITANIUM 6AL-4V      TEMP= 70. F    Q= 1.40 PSI  
E= .160E 08 PSI    FTU= 160000. PSI    FCY= 154000. PSI  
RHO= .160 LB/IN3    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04    (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.67	13	7500.	2.61	5
200.	.81	8	8000.	2.68	5
300.	.92	7	8500.	2.75	5
400.	1.00	6	9000.	2.82	5
500.	1.07	5	9500.	2.90	5
600.	1.14	4	10000.	2.97	5
700.	1.19	3	11000.	3.13	4
800.	1.25	5	12000.	3.23	3
900.	1.29	5	13000.	3.43	5
1000.	1.34	5	14000.	3.59	5
1500.	1.52	7	15000.	3.75	5
2000.	1.67	7	16000.	3.92	5
2500.	1.80	7	17000.	4.08	5
3000.	1.91	7	18000.	4.25	5
3500.	2.01	7	19000.	4.42	5
4000.	2.10	6	20000.	4.59	5
4500.	2.19	5	21000.	4.76	5
5000.	2.26	5	22000.	4.93	5
5500.	2.33	6	23000.	5.10	5
6000.	2.40	6	24000.	5.28	5
6500.	2.47	5	25000.	5.45	5
7000.	2.54	5			

SLOPE= .000161 PSF/LB/IN    CB= 1.38 PSF  
FA= 143173. PSI    TAU= 49600. PSI  
WBAR= .000161 \* QRUN + 1.38

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TABLE A-10  
RESULTING OUTPUTS

TITANIUM 6AL-4V      TEMP= 600. F    Q= 1.40 PSI  
E= .131E 08 PSI    FTU= 118000. PSI    FCY= 98000. PSI  
RHO= .160 LB/IN<sup>3</sup>    RIB SPACING= 20.0 IN  
FIXITY COEFFICIENT= 2.04    (ONE END FIXED, ONE PINNED)

QRUN	WBAR	K	QRUN	WBAR	K
100.	.72	12	7500.	2.99	3
200.	.88	7	8000.	3.09	5
300.	.99	6	8500.	3.20	5
400.	1.03	5	9000.	3.31	5
500.	1.16	4	9500.	3.43	5
600.	1.23	4	10000.	3.54	5
700.	1.29	5	11000.	3.77	5
800.	1.34	5	12000.	4.00	5
900.	1.39	5	13000.	4.24	5
1000.	1.44	5	14000.	4.48	5
1500.	1.64	7	15000.	4.72	5
2000.	1.80	7	16000.	4.97	5
2500.	1.93	6	17000.	5.22	5
3000.	2.05	5	18000.	5.47	5
3500.	2.16	6	19000.	5.72	5
4000.	2.26	6	20000.	5.97	5
4500.	2.36	5	21000.	6.23	5
5000.	2.46	5	22000.	6.48	5
5500.	2.56	5	23000.	6.74	5
6000.	2.66	5	24000.	7.00	5
6500.	2.73	4	25000.	7.26	5
7000.	2.88	4			

SLOPE= .000236 PSF/LB/IN    CB= 1.25 PSF  
FA= 97750. PSI    TAU= 36580. PSI  
WBAR= .000236 \* QRUN + 1.25

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TABLE A-II  
FORTRAN LISTING

2	2.000	REAL *4L(4), GRN(50), RA(50), INTPT
3	3.000	INTERP FI(3), FIA(50)
4	4.000	REAL *4(4)/4.1, 2.04, 29/
5	5.000	REAL *4(4)/1.5, 2.3, 7.97/
6	6.000	REAL *4(4)/12.2, 8.85, 4.7
7	7.000	INTERP VENO(7,4)
8	8.000	2/1(26TH FVDS FI*ED(1))
9	9.000	3/1(26TH FVDS FI*E(1))
10	10.000	4/1(26TH FVDS FI*E(1))
11	11.000	5/1(CASTILEVSKA DE(1,1))
12	12.000	6/1(26TH FVDS FI*E(1))
13	13.000	WRITE(1,5000)
14	14.000	REAL *10(10) FID
15	15.000	CALL 99999(FID)
16	16.000	5 READ(1,901,FVDS=250) (MATL(L),L=1,5)
17	17.000	INPUT(1)
18	18.000	IF(FIX*20.0) FIX=1
19	19.000	44 WRITE(1,8,1001) (MATL(L),L=1,5),TEMP,3,E,FTU,FCY,RH9,RS
20	20.000	5,FK(FIX),(KEP(L,FIX),L=1,7)
21	21.000	S1=.
22	22.000	S1=.
23	23.000	S2=.
24	24.000	V1=.
25	25.000	V1=.
26	26.000	IF(LIM*3T*50) LIM=50
27	27.000	45 DO 100 J=1,L1
28	28.000	IF(J*3T*10*AND(J*LE*20) 64 TA 46
29	29.000	IF(J*3T*25) 30 TO 43
30	30.000	AJ=FL9AT(J)
31	31.000	GRN(J)=AJ*10.
32	32.000	64 TA 47
33	33.000	44 JJ=J-10
34	34.000	AJJ=FL9AT(JJ)
35	35.000	GRN(J)=1000.+AJJ*500.
36	36.000	64 TA 47
37	37.000	42 JJ=J-28
38	38.000	AJJ=FL9AT(JJ)
39	39.000	GRN(J)=1000.+AJJ*1000.
40	40.000	47 Z=F*(FCV/E)**.575

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TABLE A-11  
FORTRAN LISTING (Continued)

```

41 = 41.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
42 = 42.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
43 = 43.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
44 = 44.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
45 = 45.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
46 = 46.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
47 = 47.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
48 = 48.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
49 = 49.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
50 = 50.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
51 = 51.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
52 = 52.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
53 = 53.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
54 = 54.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
55 = 55.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
56 = 56.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
57 = 57.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
58 = 58.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
59 = 59.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
60 = 60.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
61 = 61.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
62 = 62.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
63 = 63.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
64 = 64.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
65 = 65.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
66 = 66.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
67 = 67.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
68 = 68.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
69 = 69.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
70 = 70.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
71 = 71.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
72 = 72.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
73 = 73.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
74 = 74.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
75 = 75.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
76 = 76.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
77 = 77.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
78 = 78.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
79 = 79.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z
80 = 80.000 IF (Z/5.0.LF.FTU) FCC=.1215*Z

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FORTRAN LISTING (Continued)

```

81 - 31.000 TS=TS*(TS-TS1)*(1.-RATIO)/(RATIO-0.1)
82 - 32.000 IF(TS-LE.0.) TS=0.8*TS1
83 - 33.000 R1=RATIO
84 - 34.000 TS1=TS
85 - 35.000 GO TO 50
86 - 36.000 60 TS1=TS
87 - 37.000 R1=RATIO
88 - 38.000 N=2
89 - 39.000 TS=TS/RATIO
90 - 40.000 GO TO 50
91 - 91.000 75 CONTINUE
92 - 92.000 85 IF(TS-LT.0.01) IS=0.01
93 - 93.000 TFC=2*CR*TS
94 - 94.000 100 CONTINUE
95 - 95.000 WBAR(J)=144.*TFC*RLA
96 - 96.000 150 CONTINUE
97 - 97.000 190 CONTINUE
98 - 98.000 DO 200 J=10,LIM
99 - 99.000 SC=SC+1.
100 - 100.000 S1=S1+GRUN(J)
101 - 101.000 S2=S2+GRUN(J)**2.
102 - 102.000 V0=V0+WBAR(J)
103 - 103.000 V1=V1+GRUN(J)*WBAR(J)
104 - 104.000 200 CONTINUE
105 - 105.000 DEN=SC*S2-S1*S1
106 - 106.000 ANUM=V0*S2-S1*V1
107 - 107.000 BNUM=SC*V1-V0*S1
108 - 108.000 INTOPT=ANUM/DEN
109 - 109.000 SLAPPF=BNUM/DEN
110 - 110.000 FA=RLA*144./SLARE
111 - 111.000 TAU=.31*FTU
112 - 112.000 XJJ=FLRAT(LIM)/2.
113 - 113.000 XJ=FLRAT(LIM/2)
114 - 114.000 JJ=LIM/2
115 - 115.000 JADD=0
116 - 116.000 IF(XJJ-ET*XJJ) JADD=1
117 - 117.000 JI=LIM/2+JADD
118 - 118.000 DO 220 J=1,JJ
119 - 119.000 220 WRITE(12,100)

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**TABLE A-11**  
**FORTTRAN LISTING (Continued)**

120	=	120.000	1.000(J),WBAT(J),K(J),GRU(J+JI),WBAR(J+JI),K(J+JI)
121	=	121.000	IF(JMOD-5.E-1) WRITE(198,999) GRUN(JI),WBAR(JI),K(JI)
122	=	122.000	WRITE(1,8,110)SLOPE,INICPT,FA,IAU,SLEPE,INICPT
123	=	123.000	GO TO 6
124	=	124.000	250 STEP
125	=	125.000	300 FORMAT('WHAT FILE CONTAINS THE DATA ')
126	=	126.000	901 FORMAT('A')
127	=	127.000	990 FORMAT('X,F10.0,F11.2,I6)
128	=	128.000	1000 FARNAT('X,F10.0,F11.2,I6,XX,F10.0,F11.2,I6)
129	=	129.000	1001 FARNAT('M1,5X,5A4,XX,TEMP=F5.0,F'3X,IQ=F6.2
130	=	130.000	1,'PSI '//5X,F=F'E10.3,'PSI',3X,FTU=F8.0,'PSI',2X
131	=	131.000	2,FCY=F8.0,'PSI',//5X,RH=F5.3,'LB/IN',3X,
132	=	132.000	3,TIP SPACI=G=F5.1,'IN',//5X,FIXITY COEFFICIENT=F5.2
133	=	133.000	4,5X,7A4///
134	=	134.000	5,7X,IQR=' ,3X,WBAR',4X,K',14X,'GRUN',8X,'WBAR',4X,K'//)
135	=	135.000	1100 FARMAT('/EX,'SLOPE=F8.6,' PSF/LB/IN',5X,'CB=F8.2,
136	=	136.000	X' PQF'//5X,FA=F8.0,'PSI',5X,TAU= 'F8.0,' PSI'//5X
137	=	137.000	5,1,PAR=F8.0,' * GRUN + ',F5.2)
138	=	138.000	END